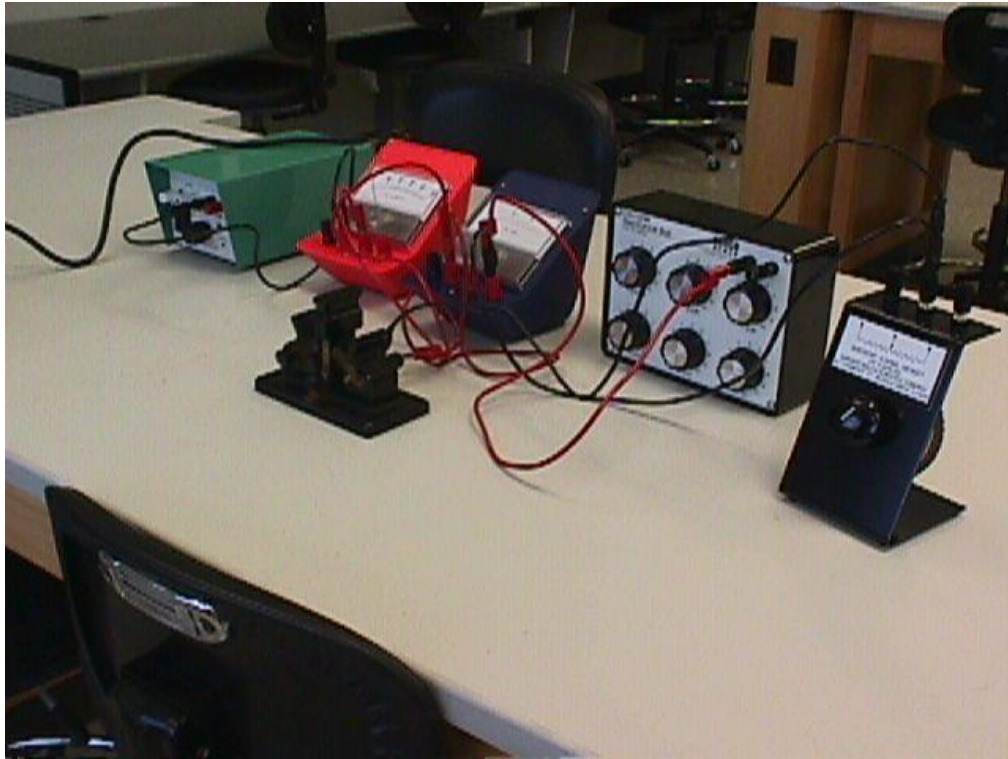


Physics 2121 Laboratory Manual



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The following is a list of experiments prepared for Physics 2121, General Physics Laboratory II. These experiments are performed in room 301 of the E. E. O'Banion (New) Science Building. Accompanying the experiments are suggested pre-lab activities that provide an orientation to each lab; these are provided before the main write-up. The purpose of the pre-lab is to get students to think ahead to the subsequent experiment, so as to arrive better prepared on the day of the experiment. A set of 10 experiments is used in the "standard list" of experiments, but the individual instructor may switch one or two of them for another on the list (or for exercises not included in this manual, "Instructor's Choice"), or may add one or more to the list. Several of these labs involve use of PASCO computer interface equipment which works with the Dell computers in the lab. In general, the computerized version of a particular lab (when applicable) is presented alongside the traditional version, giving the instructor a choice between the two for that particular lab. A tutorial for using the computers and the computer-interfaced equipment is located in a separate manual kept in room 305.

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Introduction (to this Document and the Labs)

Introduction

This laboratory manual has descriptions of the laboratories which you will be doing this semester. It also explains some of the concepts required to be understood in order to successfully complete this course and provides examples from everyday life illustrating the concepts. This laboratory manual is the required reading material for this course.

The student (you...) will be learning how to apply the scientific method in the laboratory setting. Science is the study of the interrelationships of natural phenomena and of their origins. The scientific method is a paradigm that uses logic, common sense, and experience in the interpretation of observations. The underlying basis of the scientific method is to understand through repeatable experiments. No theory is held to be tenable unless the results it predicts are in accord with experimental results.

A major problem is: how does one quantify data so that experiments can adequately be compared? Physicists try to apply a rigorous method of error analysis, and then compare results with respect to the inherent experimental errors. If two experiments produce results that are the same to within experimental error, then we say that the experiments have validated each other.

Error analysis

It is up to your instructor whether some form of error analysis will be included in your lab assignments. It is recommended for the University Physics Laboratories, but not necessarily recommended for the General Physics Laboratories. In the event the instructor includes some form of error analysis in the course work, a brief discussion on error propagation follows.

In physics we often do experiments where we wish to calculate a value that has a functional dependence on some measurable quantities, for example:

$$y = f(x, z) \\ \text{or} \quad y = f(x_1, x_2, \dots, x_n)$$

In some cases, we wish to determine how close our experimental value is compared to the published result. This is usually performed by finding the percent difference between the experimental value and the theoretical value. The percent difference is given by:

$$\%diff = \left| \frac{(\text{experimental} - \text{theoretical})}{\text{theoretical}} \right| \times 100\%$$

NOTE: Technically the term “percent difference” refers to the difference between a measured or experimentally determined value and a theoretical or reference value. “Percent error” is the difference between two measurements of the same value made by two different methods.

Errors in measurement can readily be obtained in the following ways:

1. If only one measurement was taken, use ½ the smallest scale division of the measuring device.
2. If multiple measurements were taken:
 - use standard deviation function on your calculator.
 - or use the standard deviation formula:

$$\sigma_x = \sqrt{\frac{1}{n-1} \left(\sum_{i=1}^n (x_i - \bar{x})^2 \right)} \quad \bar{x} = \frac{\sum_{i=1}^n x_i}{n}$$

Experimental Errors

There are two kinds of errors:

1. systematic: associated with particular measurement techniques
 - improper calibration of measuring instrument
 - human reaction time
 - is the “same” error each time. This means that the error can be corrected if the experimenter is clever enough to discover the error.
2. random error: unknown and unpredictable variations
 - fluctuations in temperature or line voltage
 - mechanical vibrations of the experimental setup
 - unbiased estimates of measurement readings
 - is a “different” error each time. This means that the experimenter cannot correct the error after the data has been collected.

These errors can be made in two ways:

1. Personal: from personal bias or carelessness in reading an instrument (e.g., parallax), in recording observations, or in mathematical calculations.
2. External: from the natural limitations of the physical devices. Examples are: old and misused equipment, finite accuracy of measurement devices, heat flow, extraneous electric fields, vibrations, etc.

Accuracy: how close to the true value is the result?

Precision: how much spread is in the data?

- the more precise a group of measurements, the closer together they are
- high precision **does not** necessarily imply high accuracy

Significant Digits ...

1. exact factors have no error (e.g., 10, π)
2. all measured numbers have some error or uncertainty
 - this error must be calculated or estimated and recorded with every final expression in a laboratory report

- the degree of error depends on the quality and fineness of the scale of the measuring device 3
- Use all of the significant figures on a measuring device. For example, if a measuring device is accurate to 3 significant digits, use all of the digits in your answer. If the measured value is 2.30 kg, then the zero is a significant digit and so should be recorded in your laboratory report notes.
- keep only a reasonable number of significant digits
 - e.g., $136.467 + 12.3 = 148.8$ units
 - e.g., 2.3456 ± 0.4345634523 units $\rightarrow 2.3 \pm 0.4$ units
 - NOTE: hand-held calculators give answers that generally have a false amount of precision.

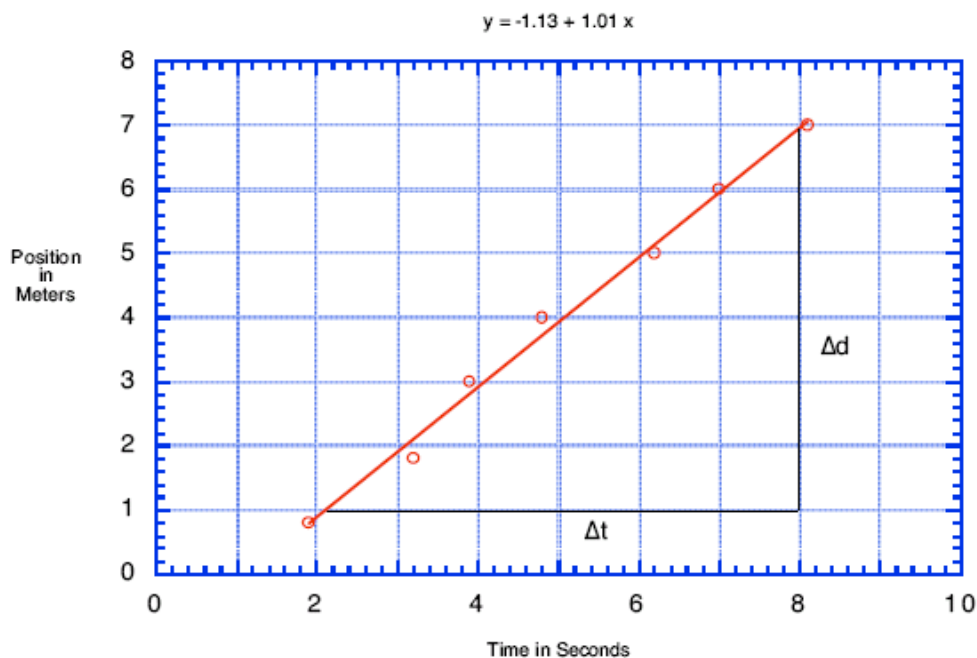
It is good practice to ensure that you round these values correctly. As a rule, the final answer should have no more significant digits than the data from which it was derived.

Graphing Techniques

1. Graphs are either to be done on a computer (using either Excel or the graphing utility of Data Studio) or on quadrille-lined paper, for example, engineering paper.
2. We draw graphs for the following reasons:
 - to see the functional dependence, that is, does it look like a straight line, a curve, or random data
 - to average out the data
 - to fit data to the linear hypothesis, that is, the data is of the form:

$$y = a + bx$$
3. You will be asked to plot a graph of the form “y versus x” (We say y versus x rather than x versus y because we write the equation in the form: $y = a + bx$ and we usually read from left to right.) The first variable goes along the ordinate (i.e., the vertical axis) and the second is placed along the abscissa (i.e., the horizontal axis).
4. Use a meaningful graph title. Use meaningful axis titles that include the units of measurement.
5. Use appropriate scales for the axis that are easy to read and will allow the data to most nearly fill the entire graph. Do not use categories as axis labels. If practical include the origin, that is, the point $\{0, 0\}$, at the lower left of the graph. However, the origin should be suppressed if the data is bunched a long way from zero.
6. Take a set of data points by measuring a value for y for each given value of x.
7. Draw the “best fit” straight line—the line that most nearly goes through all the points. Half the points should be above the line and half should be below the line. Do not force the line to go through the origin. (Unless $\{0, 0\}$ is a measured data point.)
8. Example graph (next page):

Calculation of Velocity



$$\text{Slope} = \frac{\Delta d}{\Delta t} = v = \frac{6.9 \text{ m} - 1.0 \text{ m}}{8.0 \text{ s} - 2.2 \text{ s}} = 1.02 \text{ m/s}$$

9. Slope calculations:

- Use a large baseline on the graph to find the Δx and Δy values
- A large baseline will increase the accuracy of your calculations
- In general you should do the slope calculations on the graph
- Draw the baseline along some convenient ordinate starting from the best-fit straight line— do not start from a data point!

10. If you use a computer-graphing package, ensure that you use it correctly. Be wary of the cheap graphics packages that will graph out the x values as equally spaced categories. Do not just join the points together; you require a best-fit straight line. Ensure that there are enough grid lines so that a reasonable slope calculation can be performed. Better still, use a graphics package, which does both the best-fit straight line and the slope, and intercept calculations for you. The above graph is an example as to how you are to plot acquired data. Note that the graph has the following attributes:

1. Each axis has an informative title that contains units of measurement.
2. There is a graph title.
3. The axes are computed such that the data nearly covers the complete graph.
4. There is a “best-fit” straight line that most nearly goes through all of the data points.
5. The graph is clearly linear because the data “looks” straight, and is a good linear fit because all of the data points are near the best-fit straight line.
6. Since the data is linear it can be parameterized with the following equation:

$$x = x_0 + vt$$

7. This equation is similar to the standard equation of a straight line:

$y = a + bx$, where a is the y-intercept and b is the slope.

8. Compare the above two equations and note that the coefficients are equal, that is: $a = x_0$, $b = v$. The value of the y-intercept is equal to the initial position and the value of the slope is equal to the velocity.
9. The slope, which is a representation of the average velocity, has been calculated as 1.02 m/s. The best-fit data for this graph using a least-squares algorithm is printed at the top of the graph. Its value for the slope is slightly less than the calculated value, but is the more accurate value. To within two significant figures, the values for the slopes are the same, and only two significant figures were used in the slope calculation. However, it is important to keep the third significant figure for future calculations to decrease cumulative round off errors.
10. Note well, the best fit straight line does not extrapolate through the point $\{0,0\}$ and so either the initial position of the device is less than zero, or there is some distortion near zero, or else there is a systematic error.

Laboratory Report Format

The finer details of the Laboratory Report Format may vary from instructor to instructor, but each will use a format similar to that described below. The student will hand in written or typed reports. If you type the report, but do not have access to a proper equation writer, then it is better to leave blank spaces and fill in the equations by hand. For example: $\sqrt{x + 2}$ is not the same as $\sqrt{x} + 2$, nor is x^2 an acceptable substitute for x^2 . Ambiguous equations are much worse than hand-written equations. Students are expected to use the following laboratory report format:

Group Number:

Date:

Group Members:

Object: What is to be done in this experiment.

Apparatus: Apparatus used to perform the experiment.

Theory: The calculation equations used along with meaning of the symbols and units used. Equations can be neatly hand written.

Data: Raw data in tables should be placed in this section. Sample calculations should be shown. Error calculations should be shown.

Discussion: Include a discussion of some of the sources of experimental error or uncertainty. If appropriate, should also include a comparison of various experimental errors.

For example: We found that our value of the density, within one standard deviation, has a range of 2.68 to $2.78 \times 10^3 \text{ kg/m}^3$. The quoted value of the density for aluminum falls within this range, and no other material densities fall within this range, so our cylinder appears to be made of aluminum.

Conclusion: Short but comprehensive. Was the object of the experiment met?

For example: The density of the cylinder was found to be $(2.73 \pm 0.05) \times 10^3 \text{ kg/m}^3$. We selected aluminum as the material composing our cylinder because the density of aluminum, $2.70 \times 10^3 \text{ kg/m}^3$, is within the experimental error of our calculated density.

Safety Reminder

It will be necessary to follow procedures to ensure safety in each lab. Most labs do not present any significant danger, but some will require certain safety measures to be followed. The general recommendation is to follow all safety instructions, including those posted on the wall of the room you are in; if additional special safety guidelines are needed, they will be printed for each lab needing them.

Each student, student assistant, and instructor that uses the lab is required to receive a safety briefing before beginning laboratory exercises. More details on laboratory safety for Physics II laboratories are provided in the next chapter of this Laboratory Manual.

Laboratory Safety Information

Safety in the laboratory is very important. The experiments performed in the laboratory are designed to be as safe as possible, but caution is always advised concerning the use of the equipment. **When you arrive at the start of each class meeting, it is very important that you do not touch or turn on the laboratory equipment until it has been explained by the professor and permission has been granted to get started.** The equipment for the labs are set up for you in advance, so resist the urge to play with the equipment when you arrive, as you may hurt yourself or others, or damage the equipment.

While the experiments done in Physics II (primarily electricity and magnetism) are generally safe, it is always important to be cautious when using equipment, especially if you are unfamiliar with the equipment. If you have any questions about the safety of a procedure or of the equipment, ask your instructor before handling the equipment. Some specific exercises in the laboratory do pose minor safety risks (e.g. labs that deal with electric circuits), and guidelines related to these are presented with the write up for these particular labs. In fact, for many of the experiments, the laboratory write-up contains a section on safety specific to that activity; the safety section should be read prior to starting the experiment and followed carefully throughout. When an electric circuit is involved it is vital that you do not power a circuit until you verify with the instructor that it is set up correctly, and then only when the instructor gives the go-ahead to do so. Not following instructions may result in personal injury, damage to the equipment, or both.

Although we do not use chemicals in the physics laboratories, we do use dry ice and liquid nitrogen, both of which present hazards do to their extreme coldness. Extra caution is strongly advised when using these substances. You will be dipping a constant-volume pressure apparatus into dry ice, then liquid nitrogen, each of which will have a student laboratory assistant or faculty member stationed so as to prevent accidents. Be careful not to splash any liquid nitrogen on yourself, or touch any of it or the dry ice as severe frostbite could result. In addition to the electricity and the cold materials, other hazards may come from broken glass or thermometers; in the event of such, these should be cleaned up by the laboratory assistant or the instructor.

Safety is important for the equipment as it tends to be expensive and oftentimes delicate. The equipment is tested and set up prior to the laboratory period, but if you have any doubts about the functionality of the equipment or the way that it is set up, it is important to ask the instructor prior to conducting the experiment. If a piece of equipment is broken during an experiment, promptly notify your instructor or laboratory assistant who will remove the broken apparatus to a designated place and replace it with functioning equipment. ***Do not*** try to fix the equipment yourself.

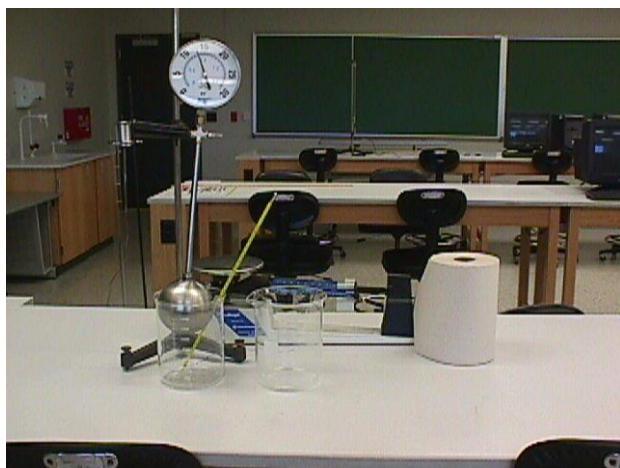
All Laboratory Students, Assistants, Faculty, and Staff must abide by the following safety rules when using the Physics or Physical Science Laboratories. This list may be modified as deemed appropriate for specific situations.

- Follow directions carefully when using any laboratory apparatus to prevent personal injury and damage to the apparatus.
- The instructions on all warning signs (including that given in writing on the walls and within the laboratory manuals, as well as verbally given by faculty and other laboratory personnel) must be read and obeyed.
- Wear safety goggles, provided by the department, for the Absolute Zero laboratory, especially when working near Liquid Nitrogen.
- Each student MUST know the use and location of all first aid and emergency equipment in the laboratories and storage areas.
- Each student must know the emergency telephone numbers to summon the fire fighters, police, emergency medical service or other emergency response services. For your convenience, these are posted at several locations near entry/exit points around the room.
- Each student must be familiar with all elements of fire safety: alarm, evacuation and assembly, fire containment and suppression, rescue and facilities evaluation.
- Use caution when working with hot plates, steam generators, open flames, and the heat lamps.
- Laboratory walkways and exits must remain clear at all times.
- Keep magnets away from computers, computer disks, and your wallet or anything containing a magnetic strip such as your ID or credit cards.
- Be very careful when handling hot water; do not touch the beaker, the hot water, the hot plate, or any other container of hot water, and ensure the hot plate does not get wet; and wear gloves and/or use tongs when handling containers that have hot water.
- Glassware breakage and malfunctioning instrument or equipment should be reported to the Teaching Assistant or Laboratory Specialist. It is best to allow the Teaching Assistant or Laboratory Specialist to clean up any broken glass.
- All accidents and injuries MUST be reported to the Laboratory Specialist or Faculty teaching affected lab section. An Accident Report MUST be completed as soon as possible after the event by the Laboratory Specialist.
- No tools, supplies, or other equipment may be tossed from one person to another; walk the item in question to the recipient and hand it to them.
- Although the voltages and currents used in our electricity labs are low, it is best to be cautious when working with circuits: make sure the power supply is off AND unplugged when assembling or disassembling a circuit. Ensure the circuit is assembled properly before applying power to prevent damage to the equipment.
- When using the ammeters and voltmeters in a circuit, and the following is a good habit to get into in general when using (failure to do so could result in damage to the meters):
 - Be very careful in the use of the meters. Start with the rheostat fully on (if your circuit is connected to one).
 - Use the largest scale on the meter then work your way down.
- When varying the resistance of a circuit, make sure that the resistance does not become small enough to burn out the meter.
- Use caution with lasers: do not point them at any person and do not look into the laser beam as blindness can result.
- There is to be no eating or drinking in the laboratory (professor included) and no applying cosmetics, combing of hair or other grooming activity.

- Open-toed shoes are discouraged in the laboratory (lab assistants and professor included), as weights, liquid nitrogen, dry ice, or other objects may accidentally drop on people's feet; ordinary footwear provides a measure of protection from such instances.
- Casual visitors to the laboratory are to be discouraged and MUST have permission from the Teaching Assistant, Faculty Instructor of the section in question, or Laboratory Specialist to enter. All visitors and invited guests MUST adhere to all laboratory safety rules. Adherence is the responsibility of the person visited.
- Location of PPE (Personal Protection Equipment):
 - Safety goggles are kept in the drawer marked "goggles".
 - A first aid kit is available near the sink toward the front of the lab room.

In addition, the laboratory manuals contain elements of the above as they pertain to each particular experiment.

Laboratory 1—Finding Absolute Zero



Purpose

The purpose of this exercise is to determine the absolute zero point and find the relation between pressure, volume, and temperature in a gas.

Introduction and Theory

Boyle's law states that the pressure of a gas in a container is related to the volume of the gas. In other words, as the volume changes, the pressure changes. For a given amount of a gas at a fixed temperature the pressure of the gas is inversely proportional to the volume. One way

to verify this is to graph the inverse of gas volume versus gas pressure.

The most common states of matter found on Earth are solid, liquid and gas. The only difference among all these states is the amount of movement of the particles that make up the substance. What determines the state of matter is the random movement of the particles that comprise the substance relative to the intermolecular forces. Temperature, T , is the measure of the average kinetic energy of the particles. Specifically,

$$T = \frac{2}{3k} \left(\frac{1}{2} \overline{mv^2} \right) \text{ or } \overline{KE} = \frac{3}{2} kT$$

Particles with a large kinetic energy tend to collide frequently and move apart. Intermolecular forces tend to pull particles toward each other.

In an "ideal gas" there are no intermolecular forces. In practice, an "ideal gas" is sufficiently dilute that collisions are infrequent and the intermolecular forces are not effective. Real gases at room temperature and pressure behave as if their molecules were ideal. However, at high pressures or low temperatures intermolecular forces can overcome the kinetic energy of molecules and the molecules can capture one another.

For an "ideal gas", kinetic theory can be used to show that the pressure of a gas is proportional to the number of molecules per unit volume and to the average translational kinetic energy of the molecules, $\frac{1}{2} \overline{mv^2}$. As defined above, temperature is a measure of the average kinetic energy.

Thus, one obtains the ideal gas law, namely,

$$PV = NkT$$

where $k = 1.38 \times 10^{-23} \text{ J/K}$ is Boltzmann's constant, P is the gas pressure, V is the gas volume, T is the temperature in degrees Kelvin, and N is the number of molecules. Note, dividing both sides by the volume, one obtains $P = nkT$, where n is the density. When T and N are held constant, one sees that

$$P \propto \frac{1}{V} \text{ (Boyle's law)}$$

When P and N are held constant, one obtains

$$V \propto T \text{ (Charles' law)}$$

At very low temperatures, the intermolecular spacing decreases for real gases, as the forces between the molecules overcome kinetic energy. The gas becomes a liquid. At still lower temperatures and higher pressures, the liquid is forced into a rigid structure we call a solid. For the "ideal gas", this gas would continue to have a constant pressure-volume relationship. For the "ideal gas", as the temperature decreases, the volume and the pressure of the gas also decrease, with the pressure and volume maintaining a constant relationship.

Theoretically, one can use a graph of pressure versus temperature to estimate the value of Absolute Zero by finding the temperature that the pressure reaches zero.

Safety Reminder

You may be working with liquid nitrogen and / or dry ice in this lab, either of which can produce severe frostbite on contact. Be extremely careful, and use gloves and eye protection when dipping the absolute zero apparatus bulb in the liquid nitrogen dewar. One group at a time will be permitted to do this, and it is strongly recommended that this be the last element that the bulb is exposed to (that is, have the other three or four pressure / temperature measurements: room temperature, hot water, ice water, and dry ice [if available] measurements). The temperature of the liquid nitrogen is given below; DON'T insert the thermometer in the Dewar.

Laboratory #1 Report Sheet: Finding Absolute Zero

Experimenters: _____

Course: _____

Date: _____

Objective:

The objective of this experiment is (a) to verify Boyle's law and (b) to determine the absolute zero point of temperature.

Equipment

Boyle's law apparatus	1
Absolute Zero Apparatus	1
Thermometer	1
Ice for ice water bath	1
Dry ice "bath"	1
Liquid Nitrogen	1L
Bunsen Burner	1
Base and Support Rod	1
Beaker, 1.5 L	1
Buret Clamp	1

Procedure

A. Boyle's Law

Note: The Boyle's Law experiment can be performed while waiting for the absolute-zero experiment to come to equilibrium during one of the steps below.

1. Before recording P vs. V data using the Boyle's law apparatus, depress and hold the syringe at the 15 ml mark and observe what happens to the pressure reading. Does the syringe leak? In the Discussion section, discuss this problem and what technique you employed to minimize the error introduced by the leakage.
2. Take up to 10 pressure readings at different volumes using the Boyle's law apparatus.
3. Plot P vs. V^{-1} .

B. Finding Absolute Zero

1. Put about 800 mL of water in a 1.5-L beaker and put the beaker on the support stand and bring to boiling over the Bunsen burner.

- Place the thermometer near the bulb of the absolute zero apparatus on the lab table. Let the temperature (in $^{\circ}\text{C}$) and gas pressure have come to equilibrium and record the temperature and pressure.
- Carefully place the bulb of the absolute temperature apparatus in the boiling water. When the water returns to boiling (100°C) and the gas pressure achieves an equilibrium record the pressure.
- Place the bulb in the ice/ice-water bath. Let the gas come to equilibrium with the ice-water bath (0°C) and record the pressure.
- Very carefully surround the bulb of the absolute temperature apparatus with dry ice (frozen CO_2). Let the gas come into equilibrium with the dry ice (-78.5°C) and record the pressure. (Reaching equilibrium with the dry ice might take a while.)
- Very carefully place the bulb of the absolute temperature apparatus into the liquid nitrogen. Let the gas come into equilibrium with the liquid nitrogen (-196°C) and record the pressure.
- Plot pressure versus temperature in $^{\circ}\text{C}$. Determine absolute zero from the “y-intercept” of the T vs. P curve with the T axis (where $P = 0$). (Alternatively, plot P vs. T , and that absolute zero intercept is the “x-intercept”.)

Data

A. Boyle's law

P	V	$1/V$

B. Finding Absolute Zero

P	T (°C)
	100
	0
	-78.5
	-196

Data Analysis

P vs. V^{-1} plot attached.

Intercept from plot = Absolute zero (°C) = _____

Summary:

Attach a typed Conclusion section and a Discussion section.

Pre-Laboratory Exercise #2: Speed of Sound in Air

Name: _____

Course: _____

Date: _____

An organ pipe is 2.0-m long. Assume the pipe is cylindrical with one closed and one open end. (Show your calculations to obtain the answers below.)

1. What is the longest wavelength λ for a standing sound wave possible in the pipe?

Answer: _____

2. (a) What is the wavelength of the 1st overtone? Answer: _____

(b) What is the wavelength of the 2nd overtone? Answer: _____

3. If the frequency of the 4th harmonic is 290 Hz, then what is the speed of sound in the pipe?

Answer: _____

Laboratory 2—Speed of Sound in Air

(Adapted from Jerry Wilson, *Physics Laboratory Experiments*, 4th Ed, pp. 227-230, © 1994 Houghton Mifflin Company)



Purpose

The purpose of this experiment is to use resonance to measure the speed of sound in air.

Introduction and Theory

Sound is a vibration that travels through a medium as a wave. The speed of sound indicates the distance the sound travels in a given amount of time. In dry air at 20 deg C the speed of sound is 343.14 meters per second.

Speed of sound is used in determining the distance between the objects. For example consider an echo, which is the reflection of the sound wave on a barrier. The barrier can be a wall or a canyon. If we make a loud sound within a canyon; the sound waves will hit the wall of the canyon and reflect back forming an echo. The time delay between the shout and the echo corresponds to the time for the sound waves to travel to the canyon wall and back. Measurement of this time will give an estimate of one-way distance to the canyon wall. For example if an echo is heard 2.80 seconds after making the noise, then the distance to the canyon wall can be found as follows:

$$\text{Distance} = v \cdot t = 343.14 \text{ m/s} \cdot 1.4 \text{ s} = 480.396\text{m}$$

Therefore the canyon wall is 480.396 meters away.

Bats use sound waves to hunt and navigate. Bats produce and send short bursts of ultrasonic waves which hit the objects and reflect back. They detect the time delay between sending and receiving waves and approximate the distance of the objects. Automatic focus cameras use ultrasonic sound waves to determine the distance of the objects. The camera sends short bursts of ultrasonic waves which hit the objects and reflect back. A sensor detects the time it takes for the waves to return and then determines the distance of the object from the camera.

Air columns in pipes or tubes of fixed lengths have particular resonant frequencies. An example is an organ pipe of length L with one end closed, the air in the column, when driven at particular frequencies vibrates in resonance. The interference of the waves traveling down the tube and the reflected waves traveling up the tube produces longitudinal standing waves, which have a node at the closed end of the tube and an antinode at the open end. Sound travels through air at "**the speed of sound.**" Officially, the speed of sound is **331.3 meters per second** (1,087 feet per second) in dry air at 0⁰ Celsius (32⁰ Fahrenheit). At a temperature like 28⁰ C (82⁰ F), the speed is 346 meters per second.

The speed of sound changes depending on the **temperature** and the **humidity**; but if you want a round number, then something like 350 meters per second and 1,200 feet per second are

reasonable numbers to use. So sound travels 1 kilometer in roughly 3 seconds and 1 mile in roughly 5 seconds.

The resonance frequencies of a pipe or tube depend on its length L . Only a certain number of wavelengths can “fit” into the tube length with the node-antinode requirements needed to produce resonance. Resonance occurs when the length of the tube is nearly equal to an odd number of quarter wavelengths, i.e. $L = \lambda / 4$, $L = 3\lambda / 4$, $L = 5\lambda / 4$, or generally $L = n\lambda / 4$ with $n = 1, 3, 5, \dots$ and $\lambda = 4L / n$. Incorporating the frequency f and the speed v_s through the general relationship $\lambda f = v$, or $f = v/\lambda$, we have

$$f_n = \frac{nv}{4L} \quad n = 1, 3, 5, \dots$$

Hence, an air column (tube) of length L has particular resonance frequencies and will be in resonance with the corresponding odd-harmonic driving frequencies.

As can be seen in this equation, the three experimental parameters involved in the resonance conditions of an air column are f , v , and L . To study resonance in this experiment, the length L of an air column will be varied for a given driving frequency, instead of varying f for a fixed L as in the case of the closed organ pipe described above. Raising and lowering the water level in a tube will vary the length of an air column.

As the length of the air column is increased, more wavelength segments will fit into the tube. The difference in the tube (air column) lengths when successive anti-nodes are at the open end of the tube and resonance occurs is equal to a half wavelength; for example,

$$\cancel{L_1} L_2 = \frac{3\lambda}{4} \quad \text{and} \quad \cancel{L_2} L_3 = \frac{5\lambda}{4} \quad \text{for the next resonance.}$$

When an antinode is at the open end of the tube, a loud resonance tone is heard. Hence, lowering the water level in the tube and listening for successive resonances can determine the tube lengths for antinodes to be at the open end of the tube. If the frequency f of the driving tuning fork is known and the wavelength is determined by measuring the difference in tube length between successive antinodes, $\Delta L = \lambda / 2$ or $\lambda = 2\Delta L$, the speed of sound in air v_s can be determined from $v_s = \lambda f$.

The speed of sound, which is temperature dependent, is given to a good approximation over the normal temperature range by $v_s = 331.5 + 0.6T_c$ m/s, with T_c the air temperature in degrees Celsius.

Laboratory 2 Report Sheet: Speed of Sound in Air

Experimenters: _____

Course: _____

Date: _____

Objective:

The purpose of this experiment is to use resonance to measure the speed of sound in air.

Equipment:

Resonance tube apparatus	1
Tuning Forks (~500 – ~1000 Hz) stamped	3
Rubber mallet or Block	1
Meter stick	1
Thermometer	1

Procedure:

1. Raise the water level to near the top of the tube by raising the reservoir can, by depressing the can clamp and sliding it on the support rod. With the water level near the top of the tube, there should be little water in the can; if this is not the case, remove some water from the can to prevent overflow and spilling when the can becomes filled when lowering.
2. With the water level in the tube near the top, take a tuning fork of known frequency and set it into oscillation by striking it with a rubber mallet or on a rubber block. Hold the fork so that the sound is directed in the tube (experiment with the fork and your ear to find the best orientation). With the fork above the tube, lower the reservoir can. The water in the tube should slowly fall at this time, and successive resonances will be heard as the level passes through the resonance length position. It may be necessary to strike the fork several times to keep it vibrating sufficiently.
3. With the pattern of resonances approximately known, adjusting the height of the water at each of the resonances in turn. Record the height of the water for each resonance. Since only the difference in height between resonances is used, one can use the marks on the glass tube as a meter stick.
4. Repeat steps 2 and 3 with another tuning fork of known frequency.
5. Find the speed of sound and experimental error:
 - a. Compute the average wavelength for each fork from the average of the differences in the tube lengths between successive anti-nodes.
 - b. Using the known frequency for each fork, compute the speed of sound for each case.

- c. Compare the average of these two experimental values with the value of the speed of sound given by the last equation by computing the percent error (if this error is large, you may have observed the resonances of the tuning forks' overtone frequencies—consult your instructor in this case).

Data:

h = height of water at resonance; Δh = distance between successive resonances

Case 1: $f =$ _____

h	Δh

$\overline{\Delta h} =$ _____

$v_s = 2f\overline{\Delta h} =$ _____

Case 2: $f =$ _____

h	Δh

$\overline{\Delta h} =$ _____

$v_s = 2f\overline{\Delta h} =$ _____

Average $v_s =$ _____

$T_c =$ _____

$v_s = 331.5 + 0.6T_c$ m/s = _____

% difference = _____

Attach typed Conclusion and Discussion sections.

Data Sheet

1st Primary Frequency _____

Frequency Wavelength _____

	Distance (m)	Δd (m)	Wavelength
1 st resonance			
2 nd resonance			
3 rd resonance			
4 th resonance			

Show work for calculations

Average Calculated Wavelength _____m

Calculated Speed of Sound in air _____m/s

2nd Primary Frequency _____

Frequency Wavelength _____

	Distance (m)	Δd (m)	Wavelength
1 st resonance			
2 nd resonance			
3 rd resonance			
4 th resonance			

Show work for calculations

Average Calculated Wavelength _____m

Calculated Speed of Sound in air _____m/s

Recorded room temperature _____ °C

The theoretical speed of sound in air is approximately 343 m/s at 20°C. Determine the theoretical speed of sound in this classroom based on your temperature readings.

Theoretical speed of sound in air in this classroom

_____ m/s

Averaged speed of sound in air from your experiments

_____ m/s

Percent Error _____ %

Unknown Primary Frequency _____

Frequency Wavelength _____

	Distance (m)	Δd (m)	Wavelength
1 st resonance			
2 nd resonance			
3 rd resonance			
4 th resonance			

Show work for calculations

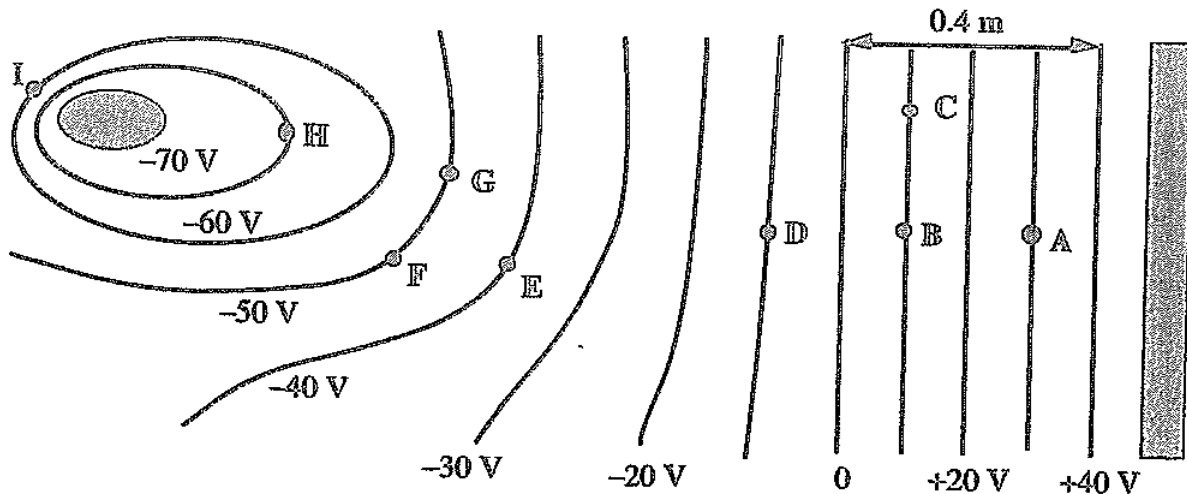
Pre-Laboratory #3: Electric Potential and Field Mapping

Name: _____

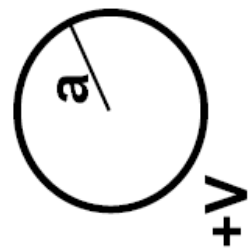
Course: _____

Date: _____

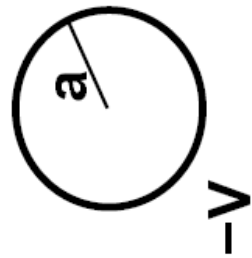
1. The sketch shows cross sections of equipotential surfaces between two charged conductors that are shown in solid black.



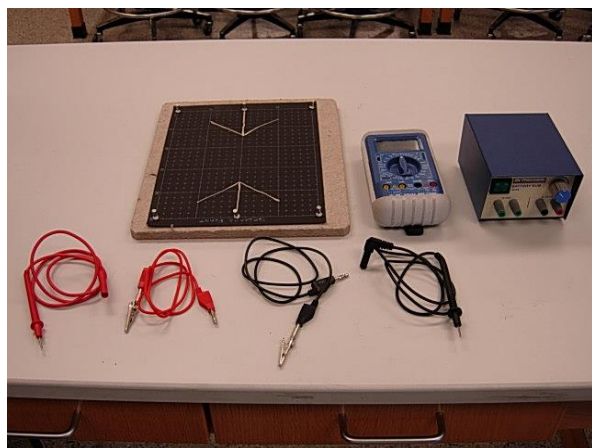
- (a) What is the potential difference between points **B** and **E**? _____
 - (b) At which of the labeled points will the electric field have the greatest magnitude? _____
 - (c) What is the electric field at point **A** (magnitude and direction)? _____
2. The sketch on the back of this page shows cross sections of two conducting spherical shells.
($a = 5.0$ cm, $b = 0.50$ m, and $V = 100$ V)
- (a) Using dashed curves draw representative equipotentials around and between the spheres.
 - (b) Using solid curves and arrows draw the electric field lines.
 - (c) What is the charge on the left sphere? _____
 - (d) What is the potential at point **P** midway between the two spheres? _____
 - (e) What is the magnitude and direction of the electric field at point **P** midway between the two spheres? _____



■ P



Laboratory 3— Electric and Potential Field Mapping



Purpose

We will investigate the nature of electric field lines by mapping equipotential lines (lines of constant potential). This lab will show you how to measure and plot equipotential lines with a voltmeter to be used for constructing the electric field which lies perpendicular to the equipotential lines.

Having completed this lab you will be able to:

1. Map equipotential lines from various shaped electrodes
2. Map the shape of electric field lines from equipotential lines

Introduction & Theory

Electric fields are defined as electric force per unit charge. This is the region where electric forces are exerted on charges. Much like a topographic map where contour lines show constant elevations, equipotential lines have identical potentials along them. That is to say, if we took any two arbitrary points along an equipotential line and calculated the differences in potential between the two points, $\Delta V = V_b - V_a$ we would get zero.

The electric field, \mathbf{E} , is defined as the electric force, \mathbf{F} , per unit charge, q_0 : $\mathbf{E} = \mathbf{F}/q_0$. Electric field is a vector and by convention points in the direction of the force on a positive charge. The electric force on a charge q is $\mathbf{F} = q\mathbf{E}$, where \mathbf{E} is the electric force per unit charge produced from a distribution of charges

$$\vec{E} = \frac{\vec{F}}{q_0}.$$

For a small displacement $\Delta \mathbf{s}$ of a charge q , the work done by the electric field on the charge is $\Delta W = \mathbf{F} \cdot \Delta \mathbf{s} = q\mathbf{E} \cdot \Delta \mathbf{s}$. (The charge's path can be built up by many such small displacements.) Note that the work performed by the electric force depends only on the starting and end points and not on the path taken. This means that the electric force is conservative, and we can define a potential energy $\Delta PE = -\Delta W$. We define an electric potential, V , as the potential energy per unit charge

The potential difference, ΔV , as a charge moves from point a to point b is $\Delta V = V_b - V_a = (\Delta PE)/q = -\Delta W/q = -\mathbf{E} \cdot \Delta \mathbf{s}$. Hence, $\Delta PE = q\Delta V = -q\mathbf{E} \cdot \Delta \mathbf{s}$, and the potential energy of a charge q in an electric field is $PE = qV$. If $\Delta \mathbf{s}$ is in the direction of \mathbf{E} , then

$$E = -\frac{\Delta V}{\Delta s}$$

Indeed, any component of \mathbf{E} is just $E_i = -\Delta V/\Delta x_i$. For example, $E_x = -\Delta V/\Delta x$ and $E_y = -\Delta V/\Delta y$. Paths of constant potential are called *equipotentials*. The electric field is everywhere perpendicular to equipotentials, points from high to low potential, and its magnitude (in $V/m = N/C$) is just the potential difference divided by the distance along the field.

The properties of conductors are fully represented by the notion of electric potential. Recall that for a static conductor:

1. The electric field is zero inside a conductor.
2. This implies that the potential is the same everywhere inside and equal to its value at the surface.
3. All excess charge must reside on its surface and is distributed according to the shape of the conductor; the surface charge density, σ , is greater where the curvature is greater.
4. The electric field is normal (perpendicular) to the surface, and its magnitude at the surface is $\sigma / (2\epsilon_0)$.

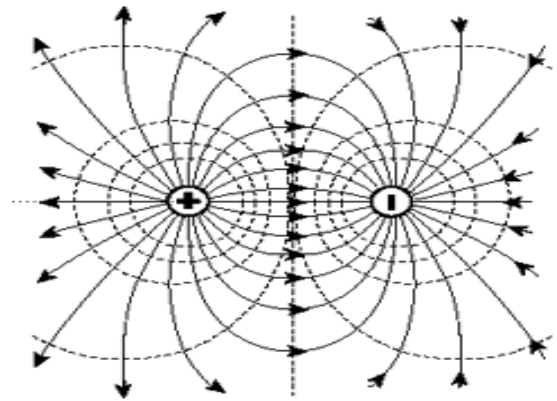
We can map electric field lines by determining either:

1. The lines of force or
2. Equipotential lines.

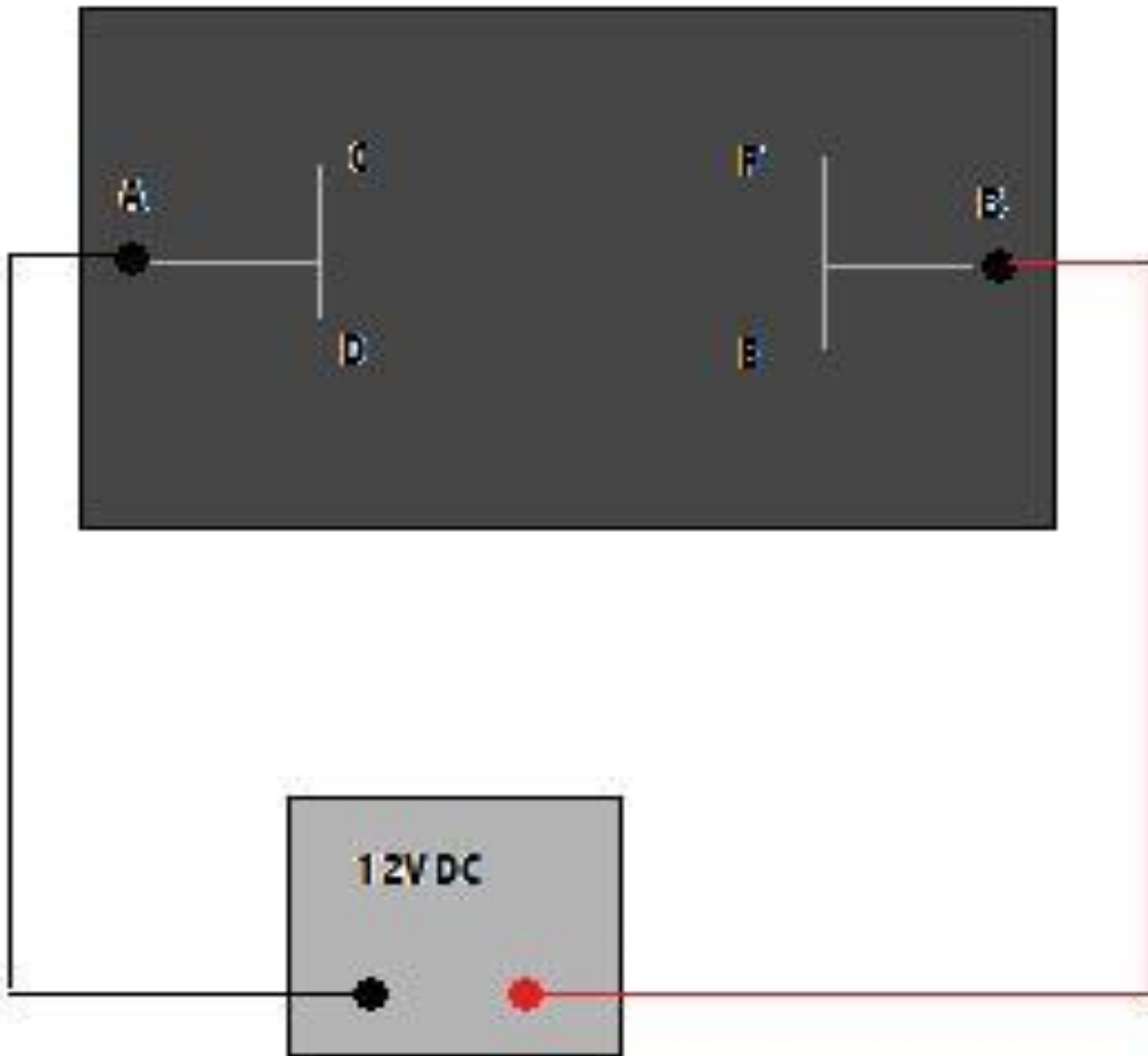
It is easier to work with equipotential lines. Having plotted sufficient equipotential lines we may then map out the electric field lines which are normal (perpendicular) everywhere to them.

If we know the potential at a discrete number of points (which is what you will measure today), then $E_x = -\Delta V / \Delta x$. If the direction is along a field line (which is perpendicular to the equipotential lines), then in that direction along the field line $E = -\Delta V / \Delta s$ where Δs is along the field line.

To the right is an example of two charges (dipole) and the associated electric field. Note the equipotential lines (dashed) are everywhere perpendicular to the electric field.



The sketch on the next page displays the correct setup of the circuit we are working with. We will have a 12V DC power supply connected to a board with conducting push pins which serve to affix the paper to the board and provide a conducting path for the electric current to flow into the paper.



SAFETY NOTE: It only takes $1/10^{\text{th}}$ of an ampere (0.1 amp) to kill a human being. This power supply can output $5/10^{\text{th}}$ of an ampere (0.5 amp). Therefore it is important to make sure you remove power (turn off the power supply) when making any adjustments to the circuit.

Laboratory #3 Report Sheet: Electric Potential and Field Mapping

Experimenters: _____

Course: _____

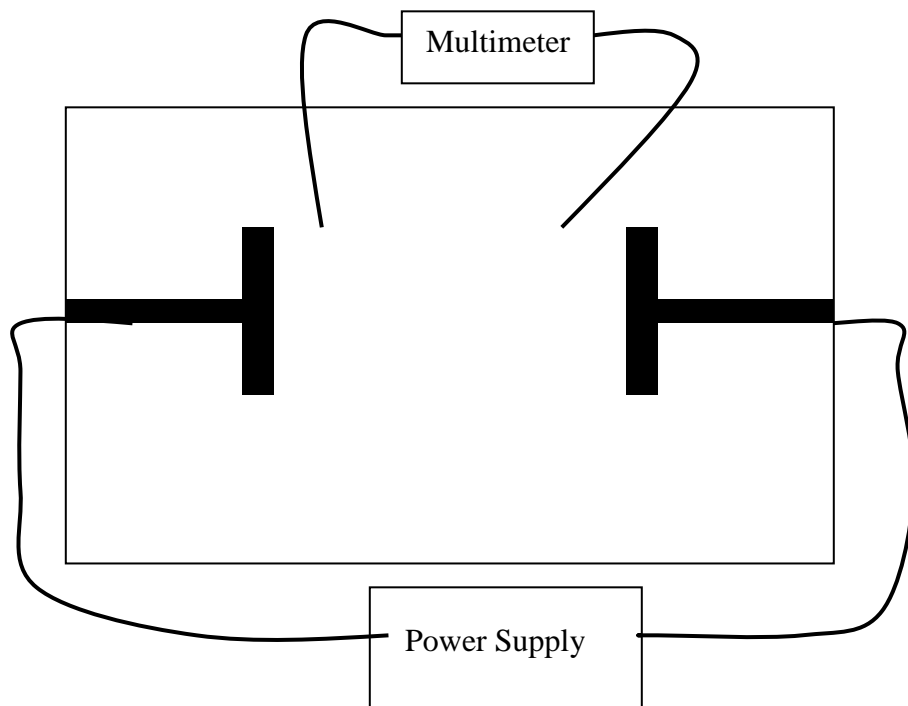
Date: _____

Purpose

We will investigate the nature of electric field lines by mapping equipotential lines (lines of constant potential). This lab will show you how to measure and plot equipotential lines with a voltmeter to be used for constructing the electric field which lies perpendicular to the equipotential lines.

Having completed this lab you will be able to:

1. Map equipotential lines from various shaped electrodes
2. Map the shape of electric field lines from equipotential lines



Equipment

Graph paper, several sheets

Conductive paper with electrode configuration, 1 to 2

Push pins, at least 6

Clip leads, 1 pair

Power supply, 1

Multimeter or galvanometer, 1

Procedure

1. Use the DC voltage setting on your multimeter to set your power supply to 6 or 9 volts DC.
2. Turn off power supply keeping the knob to the correct voltage setting.
3. Connect the assembly as shown in the figure above.
4. Turn on the power supply.
5. Using one end of your multimeter, select a point between the two electrodes noting its x and y coordinate. Use the other end to probe for the points where the voltage on the multimeter says zero, this corresponds to $\Delta V = 0$. Make a table or just plot these points.
6. Move the reference end of your multimeter to another reference point and repeat step 5 until you have sufficient equipotential lines to draw the electric field with sufficient accuracy.
7. Draw lines which are perpendicular to all equipotentials to plot your electric field lines.
8. Repeat steps 2–6 for a different electrodes configuration.

Questions for Discussion

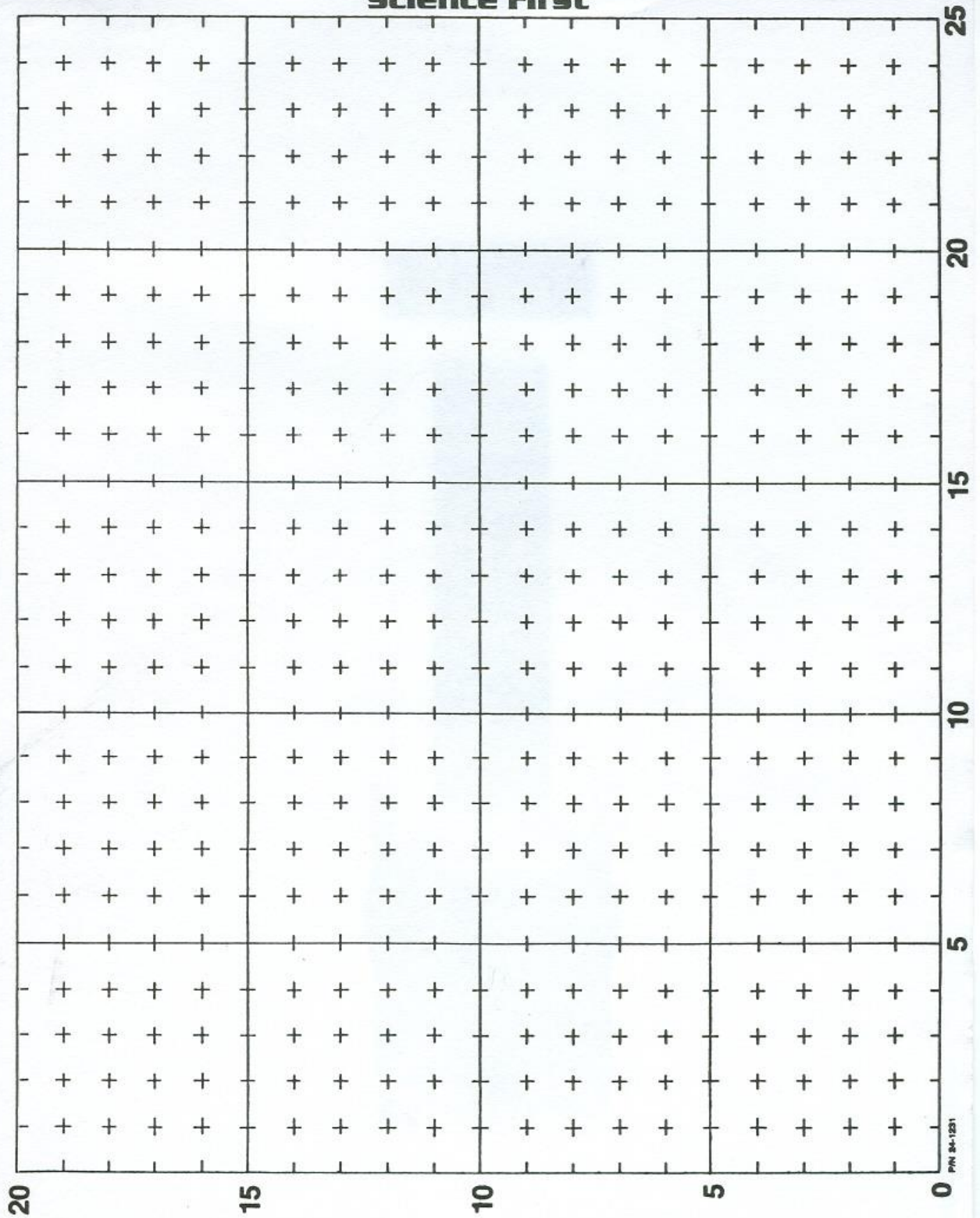
1. Calculate the electric field for at least 2 illustrative locations on each conducting sheet. Explain how you got your result and show the work.
2. In a uniform electric field the potential changes from 3.5V to 4.2V when the probe is moved in the x-direction from (5, 8) to (6.75, 8) in units of cm. Calculate the x-component of the electric field between those points. Show your work.
3. Attach your graphs to this report.

Attach a typed Summary.

Food for thought:

1. What is meant by potential difference?
2. How does electric potential compare to other potential energies?
3. What is an electric field?
4. What do you notice of the shape of the equipotential lines in comparison to the shape of the electrodes?
5. Why are electric field lines drawn perpendicular to equipotential lines?
6. What is the polarity of the E-field in your experiment?

Science First



Pre-Laboratory #4: Ohm's Law and Resistivity

Name: _____

Course: _____

Date: _____

The characteristics of five wires are given in the table.

Wire	Material	Length	Gauge
A	iron	2.0 m	#22
B	copper	2.0 m	#22
C	copper	2.0 m	#18
D	copper	1.0 m	#18
E	Iron	2.0 m	#18

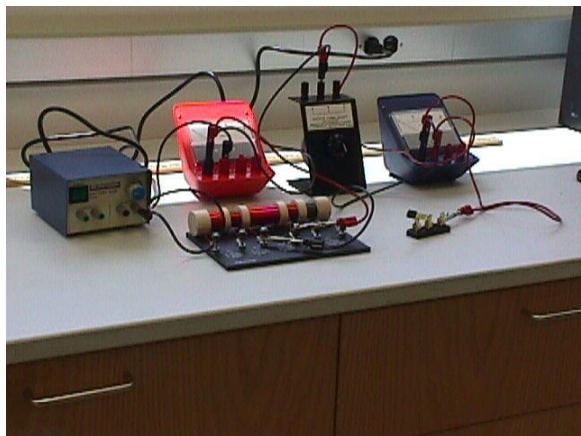
The gauge is a measure of the diameter of the wire; and #18 corresponds to a diameter of 1.2×10^{-3} m; and #22 corresponds to a diameter of 6.4×10^{-4} m. The resistivity of iron is $9.7 \times 10^{-8} \Omega \cdot \text{m}$; and the value for copper is $1.72 \times 10^{-8} \Omega \cdot \text{m}$.

1. Of the five wires, which one has the smallest resistance? _____
2. Which one of the wires carries the smallest current when they are connected to identical batteries?

3. What is the resistance of wire **B**? (Show work.) _____
4. Wire B is connected to the terminals of a 1.5-V battery. What magnitude current flows through the wire? _____

Laboratory 4—Ohm's Law and Resistivity

(Adapted from Jerry Wilson, *Physics Laboratory Experiments*, 4th Ed., pp. 353-357, © 1994 Houghton Mifflin Company)



Purpose

The purpose of this experiment is to investigate the resistivity of several different types of wires.

Introduction and Theory

Electric current is defined as the rate at which electric charge flows through a surface,

$$I = \frac{\Delta Q}{\Delta t}$$

The SI unit of current is the ampere (1 A = 1 C/s). The direction of current flow is conventionally the direction of flow of positive charge. (This sign convention is standard, although in most cases current is carried mainly by electrons. Electrons are relatively free to move in solid conductors, and having less mass, electrons undergo a greater acceleration than protons in a given electric field.)

Ohm's law states that the potential difference V across a substance is proportional to the current I flowing through it, $V \propto I$. The proportionality is the resistance R ; $V = IR$. The MKS unit for resistance is the ohm (Ω). Thus, $R = V/I$.

The resistance of an electrical conductor depends on several factors, such as its physical shape, the type of material it is made of, and the temperature. The resistance of a wire is directly proportional to its length l and inversely proportional to its cross-sectional area, A :

$$R \propto \frac{l}{A}$$

An analogy for this is the flow of water through a pipe. The longer the pipe, the more resistance to flow, but the larger the cross-sectional area of pipe, the greater the flow rate or the smaller the resistance to flow. The material property of resistance is characterized by the resistivity ρ , and for a given temperature:

$$R = \frac{\rho l}{A}$$

Resistivity is independent of the shape of the conductor, and rearranging the previous expression gives the equation for resistivity:

$$\rho = \frac{RA}{l}, \text{ with units of } \Omega\text{-m or } \Omega\text{-cm}$$

For a cylindrical wire, the cross-sectional area will be $A = \pi D^2/4$. Thus, using $R = V/I$,

$$\rho = \frac{\pi}{4} \frac{VD^2}{I\ell}$$

$$\delta\rho = \left(\frac{\delta V}{V} + \frac{2\delta D}{D} + \frac{\delta I}{I} + \frac{\delta\ell}{\ell} \right) \rho$$

Laboratory #4 Report Sheet: Ohm's Law and Resistivity

Experimenters: _____

Course: _____

Day: _____

Objective

The objective of this experiment is to verify Ohm's law and determine the resistivity of copper and constantan wire.

Equipment

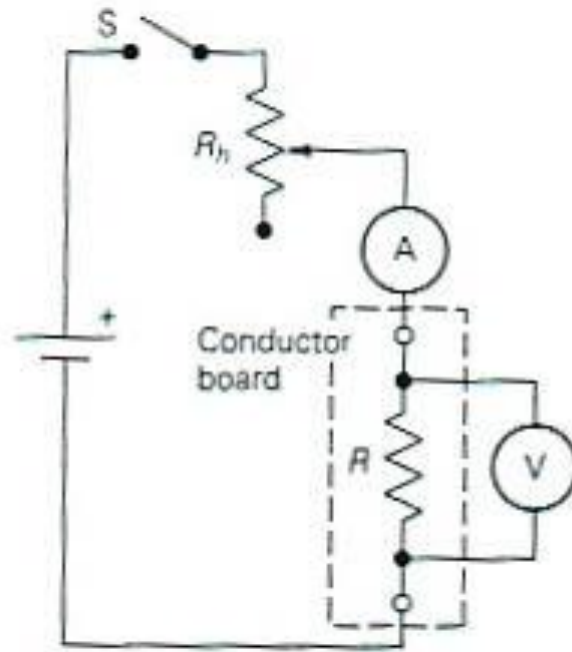
Ammeter (0-0.5 A)	1
Voltmeter (0-3V)	1
Rheostat (20 Ω)	1
Battery or power supply	1
Meter stick	1
Micrometers or Calipers	1
Conductor board or wires of various types, lengths and diameters	1 (set)

Procedure

1. Set up the circuit as shown below, with one of the wires on the conductor board in the circuit. Leave the rheostat set to the maximum resistance, and the power supply set to 0 or off, and have the instructor check the circuit before activating.
2. Turn up the DC volts of the power supply to 12V and adjust the rheostat until the current in the circuit as indicated by the ammeter is 0.5 A. Record the meter values and the DC volts back to 0 as soon as possible to prevent heating and temperature change.
3. Measure the length of the wire between the voltmeter connections and the diameter of the wire.
 - a. Measure the voltage between each terminal to get five values (remember to measure close to the spool and not at the terminals themselves)
 - b. Record L in cm and A in cm^2 so we can compare with published values more easily
 - c. The lengths are printed by each spool, and the thickness of each wire is represented by the numbers 22 (for one value) and 28 (for a thinner value)
 - d. Thus, if you carefully measure the thickness of #1 and #2, you can assume that the value of A for #1 is the same as that for #3 and #5; likewise for #2 and #4.
 - e. Thickness values are obtained by measuring as many consecutive turns as possible, making sure they are one right next to another and not skewed...count

the number (N) of turns and measure the length along N turns, divide that value by N to get the diameter of a single turn.

- f. With the value for diameter, D , compute the cross-section area, A , with the formula $A = \pi D^2/4$
4. Find the percent error of the experimental values by comparing your values with the accepted values listed below.



NOTE: For best results, the voltmeter should make contact with the resistance wire (R) about 5 cm in from the terminals, not at the terminals.

Data:

Substance	Resistivity, ρ (Ω -cm)
Aluminum	2.8×10^{-6}
Brass	7×10^{-6}
Constantan	49×10^{-6}
Copper	1.72×10^{-6}
German Silver (18% Ni)	33×10^{-6}
Iron	10×10^{-6}
Manganin	44×10^{-6}
Mercury	95.8×10^{-6}
Nichrome	100×10^{-6}
Nickel	7.8×10^{-6}
Silver	1.6×10^{-6}
Tin	11.5×10^{-6}

Ohm's Law:Wire: 4 (copper)

<i>V</i>, Voltage	<i>I</i>, Current

Slope of V vs. I , $R =$ _____, Average $V =$ _____, Average $I =$ _____Wire: 5 (constantan)

<i>V</i>, Voltage	<i>I</i>, Current

Slope of V vs. I , $R =$ _____, Average $V =$ _____, Average $I =$ _____

Resistivity:

Wire	Diameter, D	Length, l	Voltage, V	Current, I
1 (copper)				
2 (copper)				
3 (copper)				
4 (copper)			Ave=	Ave=
5 (constantan)			Ave=	Ave=

$\delta D =$ _____; $\delta l =$ _____; $\delta V =$ _____; $\delta I =$ _____

Data analysis:

Wire	ρ_{calc}	ρ_{known}	% error	% uncertainty
A, copper				
B, copper				
C, copper				
D, copper				
E, constantan				

Summary:

Attach a typed Conclusion and Discussion section, addressing any questions your professor may ask.

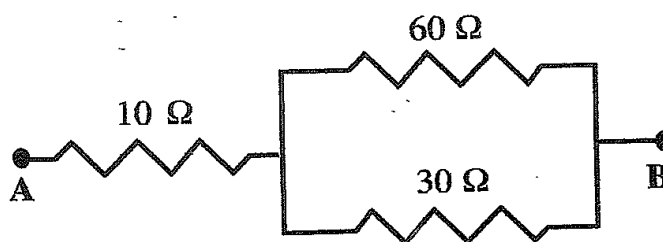
Pre-Laboratory Exercise #5: Series and Parallel Resistors

Name: _____

Course: _____

Date: _____

Three resistors are placed in a circuit as shown. The potential difference between points **A** and **B** is 30 V.



1. What is the equivalent resistance between points **A** and **B**? _____

2. Complete the following table for the potential difference and current across each of the resistors

R (Ω)	ΔV (V)	I (A)
10		
30		
60		

Laboratory 5—Series and Parallel Resistors



Purpose

The purpose of this lab is to learn how currents flow through simple linear series and parallel circuits.

Introduction and Theory

Kirchoff's rules state the conservation of energy and charge in an electrical circuit and can be used to determine the distribution of current and voltage within an electrical circuit. Kirchoff's "loop rule" expresses conservation of energy.

"Loop rule": The sum of the potential drops around any closed loop within a circuit is zero.

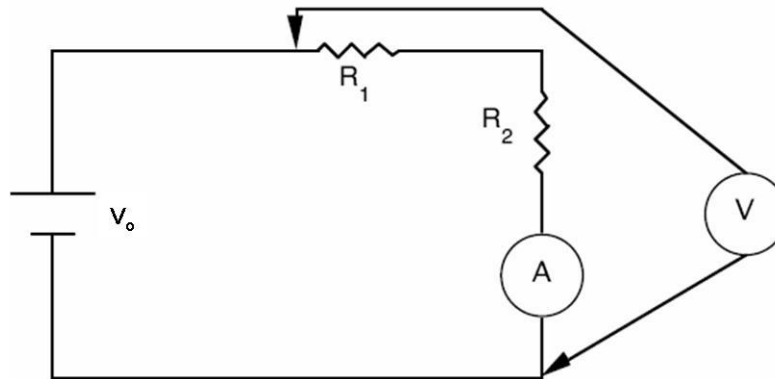
Simply put, start from any part of a circuit, go around a closed loop returning to the starting point, and the potential must return to its starting value. Kirchoff's "junction rule" expresses conservation of charge.

"Junction rule": The total current entering a junction must equal the total current leaving a junction.

A junction is an intersection of conductors (wires). If the current into a junction were different than the current leaving that junction, then charge would accumulate at the junction. This would result in an electric field along the wires directed toward or away from the charge; the charge would be accelerated away from the junction. In other word, because the charge carriers in a conductor are free, an electric field cannot be sustained within a conductor. Therefore, charge cannot accumulate at a junction.

These rules can be used to determine the equivalent resistance of combinations of resistors in series and parallel. Consider a simple series combination as diagramed below.

Schematic for a Series Circuit is shown on the next page:



V_o = applied voltage

A = ammeter

V = voltmeter

R_1 = resistor one

R_2 = resistor two

When some number of resistors are arranged in a circuit hooked together in a series connection as in the above diagram, the sum of the voltage drops across the separate resistors must equal the applied voltage:

$$V_o = V_1 + V_2 + V_A$$

Using Ohm's law, $V = IR$, and the fact that the current in the circuit must everywhere be the same, the voltage relation can be written

$$IR_{eq} = IR_1 + IR_2 + IR_A$$

where R_{eq} is the equivalent resistance of the circuit. Thus, the total resistance in the circuit is the sum of the individual resistances. (Note that the ammeter has an internal resistance that needs to be included in this experiment.)

$$R_{eq} = \sum_i R_i \quad (\text{series})$$

When a set of resistors are arranged in parallel as in the diagram below, the total current into the parallel part of the circuit is equal to the sum of the currents in each branch of the parallel circuit:

$$I_o = I_1 + I_2$$

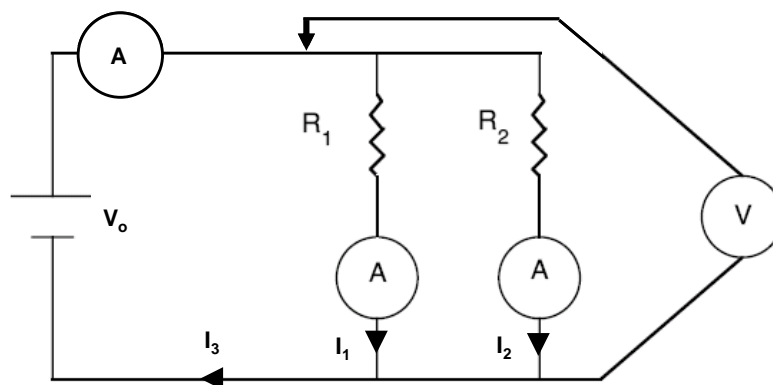
Using Ohm's law and the fact that the potential drop across each branch must be the same as the applied voltage:

$$\frac{V_o}{R_{eq}} = \frac{V_o}{R_1} + \frac{V_o}{R_2}$$

Thus, resistors in parallel are the same as the equivalent resistance:

$$\frac{1}{R_{eq}} = \sum_i \frac{1}{R_i} \quad (\text{parallel})$$

Schematic for a Parallel Circuit:



V_o = applied voltage

A = ammeter

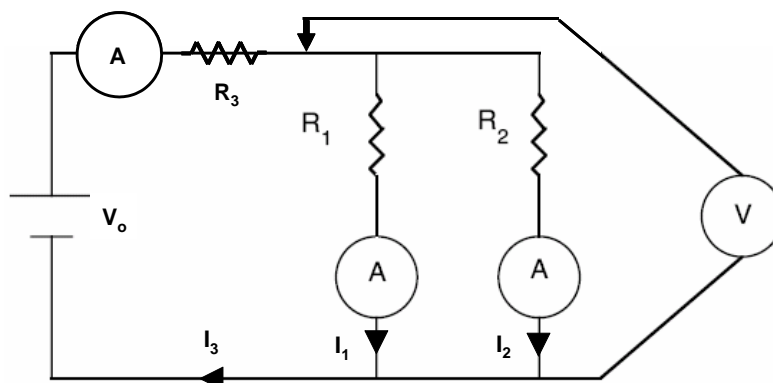
V = voltmeter

R_1 = resistor one

R_2 = resistor two

The equivalent resistance of more complicated combinations of resistors can be determined by determining the equivalent resistance of series and parallel portions of a circuit, then determining the equivalent resistance of those combinations.

The following circuit can be examined for extra credit:



The regular procedure for this lab follows. In addition, the laboratory computers in NSCI 301 are equipped with the Electronic Workbench / MultiSim utilities that are useful for supplementing the electronics-based lab exercises with quality simulation. Documentation about MultiSim and Electronics Workbench are available separately.

Optional Electronic Workbench / MultiSim Extension

Purpose or objective


To validate Ohm's Law

Equipment

Multisim software and PC

Procedure

Series resistors:

Open the Multisim program. Click on place source this symbol , which is in the upper left corner of the program. Select POWER_SOURCES from the left column, then DC_SOURCES from the right column, and then click ok. Go to anywhere on the page and left click. Then select GROUND and click ok. Place the GROUND anywhere below the POWER_SOURCE. Go to the drop down menu that has sources, click it, and then select basic. In the right column, select the value resistor necessary, and then click ok. Click ok again to select another resistor until you get the required number of resistors. Then click close to go to the circuit. Connect the circuit by going to the tip of each component, left click, and then stretch the wire to the tip of the other component then left click to attach the wire to the other component. Repeat this until the circuit is complete. See figure 1 below.

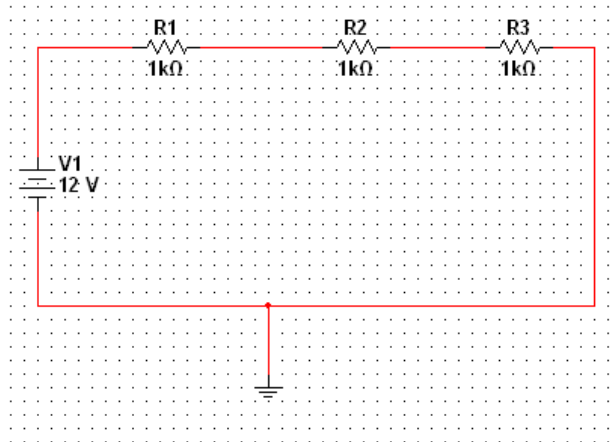



Figure 1: Resistors in series.

Now, we want to confirm Ohm's Law by measuring the voltage drop across the resistors. Let's measure the voltage drop across resistor R2 and the current between resistors R2 and R3. Click on place indicator this symbol , which is along the same row as the place sources symbol. Click on VOLTMETER in the left column and click on VOLTMETER_H in the right column, then click ok. Then click on AMMETER in the left column and click on AMMETER_H in the right column, click ok. Then click close. Connect wires from the VOLTMETER to the wire and from the AMMETER to the wire. Click on the wire below the AMMETER and click delete. The circuit should look like figure 2 below.

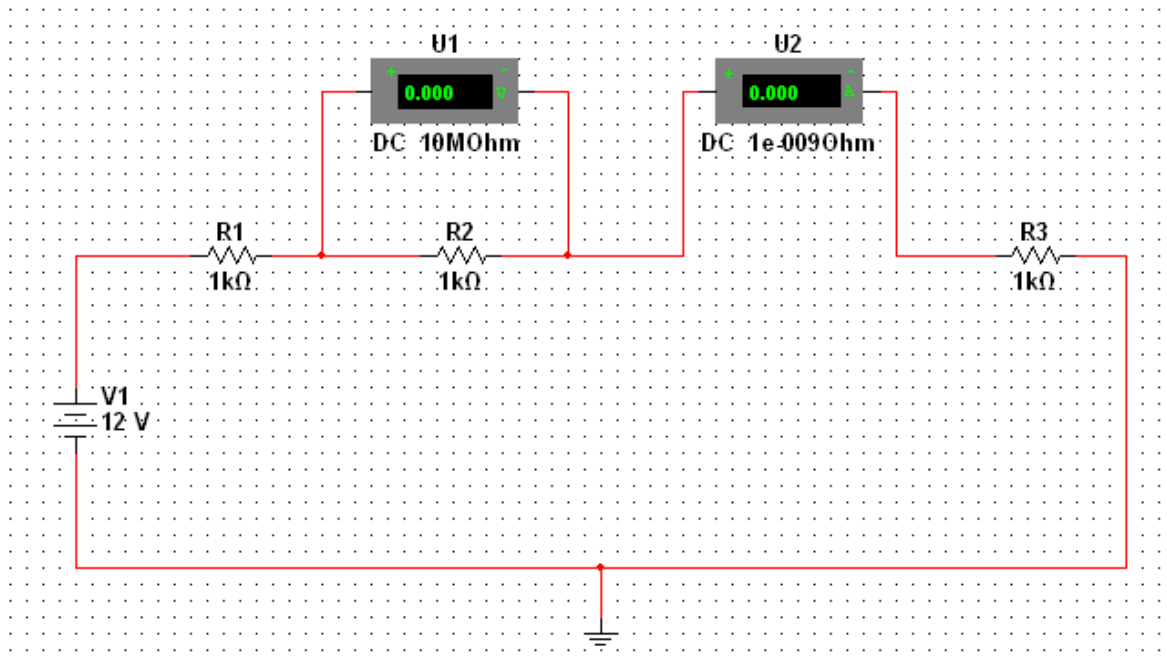





Figure 2: Circuit with VOLTMETER and AMMETER

Click the run button . Wait for a few seconds then when you see the measurements on the VOLTMETER and AMMETER, click stop . Record your measurements.

Parallel resistors

Click new . Create the schematic as shown in the figure 3 (next page). Click run and record your measurements.

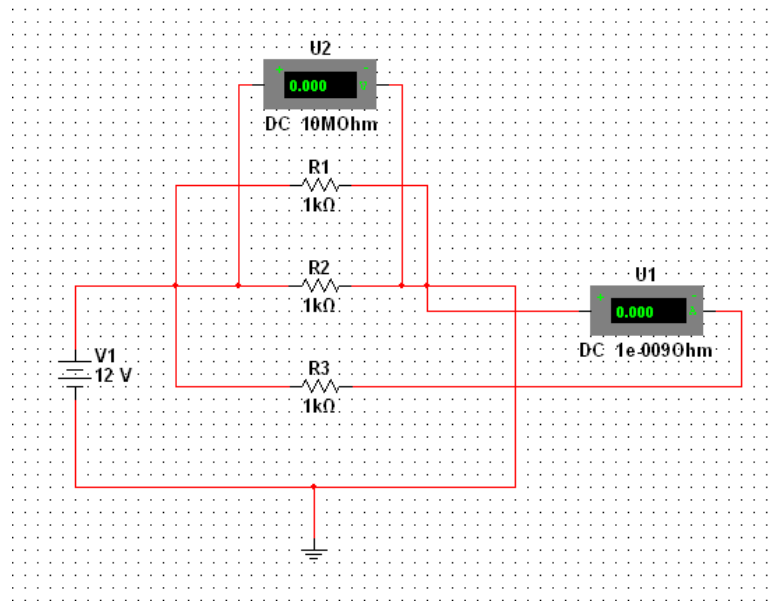


Figure 3: Resistors in parallel

Results

<u>Series:</u>		<u>Parallel:</u>	
Voltage	Current	Voltage	Current

Safety Reminder

Caution: Be very careful not to short-circuit the power supply. With too little resistance in a circuit, the current can exceed 1 A. The power supplies have a fuse that breaks the circuit if the current exceeds 1 A.

Laboratory #5 Report Sheet: Series and Parallel Resistors

Experimenters: _____

Course: _____

Date: _____

Objective:

The objective of this experiment is to determine the equivalent circuit resistance of simple combinations of resistors in series and parallel.

Equipment

Ammeter (0-0.5 A)	3
Voltmeter (0-10V)	1
Ohmmeter or multimeter	1
Rheostats (44 Ω or 177 Ω) or resistors	3
Power supply	1
Connecting wires	as needed

Procedure

We will determine the equivalent resistance of the circuits below by four methods:

- (1) Direct ohmmeter measurement of R_{eq} ,
- (2) Theoretical R_{eq} using individual ohmmeter measurements of R ,
- (3) R_{eq} from using ohm's law for circuit,
- (4) Theoretical R_{eq} from individual Ohm's law measurements of R .

1. Measure the resistance of each of the resistors and ammeters to be used below. (Note: refer to the lab write-up for schematics for each of the following circuits)

Series Circuit:

2. Set up the circuit shown above for two resistors in series. For a fixed setting for the power supply:
3. Measure the current in the circuit and the voltage drops across each of the resistors and the ammeter.
4. Measure the closed circuit voltage across the battery.
5. Remove the wires from the battery and measure the total resistance, R_{eq} , of the circuit by placing the ohmmeter leads on these two wires. (This is often called the open circuit resistance.)

Parallel Circuit:

6. Set up the circuit shown above for two resistors in parallel. For a fixed setting of the power supply:
7. Measure the total current in the circuit and the current in each branch.
8. Measure the voltage drop across each resistor and ammeter. (To avoid further complexity, call R_1 (R_2) the series combination of the resistor and ammeter in that branch.)
9. Measure the open circuit resistance, R_{eq} .

Extra Credit Circuit:

10. Set up the circuit shown above for three resistors in series and parallel. For a fixed setting of the power supply:
11. Measure the total current in the circuit and the current in each branch.
12. Measure the voltage drop across each resistor and ammeter.
13. Measure the open circuit resistance, R_{eq} .

Data

	Series Combination	Parallel Combination	Extra Credit
Ohmmeter measurements:		(incl. ammeter)	(incl. ammeter)
$R_1 \pm \delta R_1$			
$R_2 \pm \delta R_2$			
$R_3 \pm \delta R_3$	NA	NA	
$R_A \pm \delta R_A$			
$R_{eq} \pm \delta R_{eq}$			
Voltage measurements:			
$V_1 \pm \delta V_1$			
$V_2 \pm \delta V_2$			
$V_3 \pm \delta V_3$	NA	NA	
$V_A \pm \delta V_A$			
$V_o \pm \delta V_o$			
Current measurements:			
$I_o \pm \delta I_o$			
$I_1 \pm \delta I_1$	NA		
$I_2 \pm \delta I_2$	NA		

Data Analysis

Series Circuit

Equivalent resistance from ohmmeter:

$$R_{eq} = R_1 + R_2 + R_A = \underline{\hspace{2cm}} \quad \delta R_{eq} = \delta R_1 + \delta R_2 + \delta R_A = \underline{\hspace{2cm}}$$

Measured $R_{eq} \pm \delta R_{eq} = \underline{\hspace{2cm}}$

Resistance from Ohm's law:

$$R_1 = \frac{V_1}{I_o} = \underline{\hspace{2cm}}$$

$$\delta R_1 = R_1 \left(\frac{\delta V_1}{V_1} + \frac{\delta I_o}{I_o} \right) = \underline{\hspace{2cm}}$$

$$R_2 = \frac{V_2}{I_o} = \underline{\hspace{2cm}}$$

$$\delta R_2 = R_2 \left(\frac{\delta V_2}{V_2} + \frac{\delta I_o}{I_o} \right) = \underline{\hspace{2cm}}$$

$$R_A = \frac{V_A}{I_o} = \underline{\hspace{2cm}}$$

$$\delta R_A = R_A \left(\frac{\delta V_A}{V_A} + \frac{\delta I_o}{I_o} \right) = \underline{\hspace{2cm}}$$

$$R_{eq} = \frac{V_o}{I_o} = \underline{\hspace{2cm}}$$

$$\delta R_{eq} = R_{eq} \left(\frac{\delta V_o}{V_o} + \frac{\delta I_o}{I_o} \right) = \underline{\hspace{2cm}}$$

$$R_{eq} = R_1 + R_2 + R_A = \underline{\hspace{2cm}}$$

$$\delta R_{eq} = \delta R_1 + \delta R_2 + \delta R_A = \underline{\hspace{2cm}}$$

Parallel Circuit (Include R_A in series if needed.)

Resistance from ohmmeter:

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2} = \underline{\hspace{2cm}} \quad \delta R_{eq} = R_{eq} \left(\frac{\delta R_1}{R_1} + \frac{\delta R_2}{R_2} + \frac{\delta (R_1 + R_2)}{R_1 + R_2} \right) = \underline{\hspace{2cm}}$$

$$\text{Measured } R_{eq} \pm \delta R_{eq} = \underline{\hspace{2cm}}$$

Resistance from Ohm's law:

$$R_1 = \frac{V_1}{I_1} = \underline{\hspace{2cm}}$$

$$\delta R_1 = R_1 \left(\frac{\delta V_1}{V_1} + \frac{\delta I_1}{I_1} \right) = \underline{\hspace{2cm}}$$

$$R_2 = \frac{V_2}{I_2} = \underline{\hspace{2cm}}$$

$$\delta R_2 = R_2 \left(\frac{\delta V_2}{V_2} + \frac{\delta I_2}{I_2} \right) = \underline{\hspace{2cm}}$$

$$R_{eq} = \frac{V_o}{I_o} = \underline{\hspace{2cm}}$$

$$\delta R_{eq} = R_{eq} \left(\frac{\delta V_o}{V_o} + \frac{\delta I_o}{I_o} \right) = \underline{\hspace{2cm}}$$

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2} = \underline{\hspace{2cm}} \quad \delta R_{eq} = R_{eq} \left(\frac{\delta R_1}{R_1} + \frac{\delta R_2}{R_2} + \frac{\delta (R_1 + R_2)}{R_1 + R_2} \right) = \underline{\hspace{2cm}}$$

Extra Credit (Include R_A in series if needed.)

Resistance from ohmmeter:

$$R_{eq} = R_3 + \frac{R_1 R_2}{R_1 + R_2} = \underline{\hspace{2cm}} \quad \delta R_{eq} = \delta R_3 + R_{eq} \left(\frac{\delta R_1}{R_1} + \frac{\delta R_2}{R_2} + \frac{\delta(R_1 + R_2)}{R_1 + R_2} \right) = \underline{\hspace{2cm}}$$

Measured $R_{eq} \pm \delta R_{eq} = \underline{\hspace{2cm}}$

Resistance from Ohm's law:

$$R_1 = \frac{V_1}{I_1} = \underline{\hspace{2cm}} \quad \delta R_1 = R_1 \left(\frac{\delta V_1}{V_1} + \frac{\delta I_1}{I_1} \right) = \underline{\hspace{2cm}}$$

$$R_2 = \frac{V_2}{I_2} = \underline{\hspace{2cm}} \quad \delta R_2 = R_2 \left(\frac{\delta V_2}{V_2} + \frac{\delta I_2}{I_2} \right) = \underline{\hspace{2cm}}$$

$$R_3 = \frac{V_3}{I_o} = \underline{\hspace{2cm}} \quad \delta R_3 = R_3 \left(\frac{\delta V_3}{V_3} + \frac{\delta I_o}{I_o} \right) = \underline{\hspace{2cm}}$$

$$R_{eq} = R_3 + \frac{R_1 R_2}{R_1 + R_2} = \underline{\hspace{2cm}} \quad \delta R_{eq} = \delta R_3 + R_{eq} \left(\frac{\delta R_1}{R_1} + \frac{\delta R_2}{R_2} + \frac{\delta(R_1 + R_2)}{R_1 + R_2} \right) = \underline{\hspace{2cm}}$$

$$R_{eq} = \frac{V_o}{I_o} = \underline{\hspace{2cm}} \quad \delta R_{eq} = R_{eq} \left(\frac{\delta V_o}{V_o} + \frac{\delta I_o}{I_o} \right) = \underline{\hspace{2cm}}$$

Summary:

For each circuit, compare R_{eq} found by the four methods. Attach a typed Conclusion section and a Discussion section.

Optional extension may be done alongside with or after the main experiment. This is the Electronic Workbench exercise provided in the first part of the lab write up.

Extra Credit (up to 3 pts.) can be obtained for the equivalent-resistance analysis of the extra-credit circuit.

Pre-Laboratory Exercise #6: RC Circuits

Name: _____

Course: _____

Date: _____

1. In a circuit such as the one in Figure 1 (on back) with the capacitor initially uncharged, the switch S is thrown to position A at $t = 0$. The charge on the capacitor is

- (a) initially zero and finally $C\varepsilon$.
- (b) constant at a value of $C\varepsilon$.
- (c) initially $C\varepsilon$ and finally zero.
- (d) always less than $C\varepsilon$.

2. In a circuit such as the one in Figure 1 with the capacitor initially uncharged, the switch S is thrown to position A at $t = 0$. The current in the circuit is

- (a) initially zero and finally ε/R .
- (b) constant at a value of ε/R .
- (c) equal to ε/R .
- (d) initially ε/R and finally zero.

3. In a circuit such as the one in Figure 2 the switch S is first closed to charge the capacitor, and then it is opened at $t = 0$. The expression $V = \varepsilon e^{-t/RC}$ gives the value of

- (a) the voltage on the capacitor but not the voltmeter.
- (b) the voltage on the voltmeter but not the capacitor.
- (c) both the voltage on the capacitor and the voltmeter, which are the same.
- (d) the charge on the capacitor.

4. If a $5.00\ \mu\text{F}$ capacitor and a $3.50\ \text{M}\Omega$ resistor form a series RC circuit, what is the RC time constant? (Show work.) _____

5. Assume that a $10.0\ \mu\text{F}$ capacitor, a battery of emf $\varepsilon = 12.0\ \text{V}$, and a voltmeter of $10.0\ \text{M}\Omega$ impedance are used in a circuit such as that in Figure 2. The switch S is first closed, and then the switch is opened. What is the reading on the voltmeter $35.0\ \text{s}$ after the switch is opened? (Show work.) _____

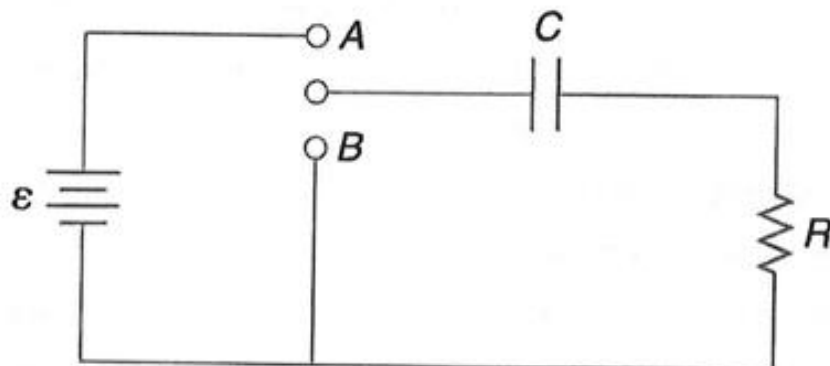


Figure 1

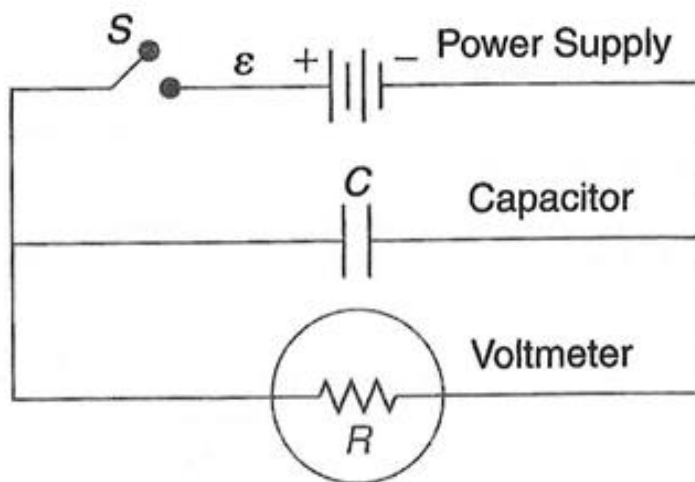


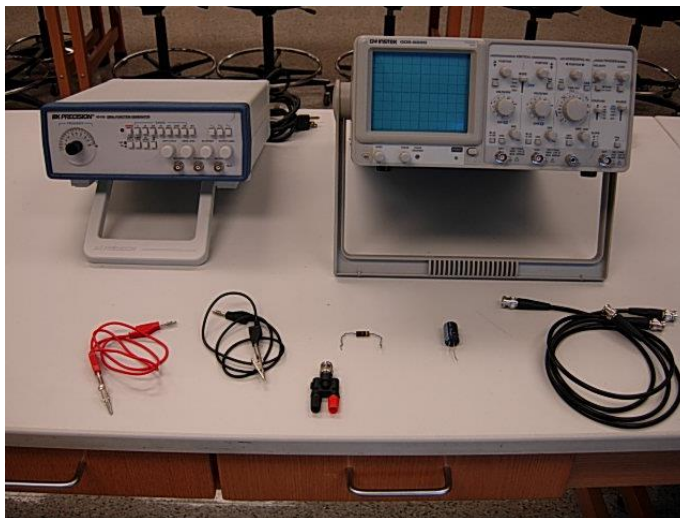
Figure 2

Laboratory 6—RC Circuits

Purpose

The purpose of this activity is study currents and voltages in RC circuits. We will use a Resistor and a Capacitor to study the capacitor's transient response as it is charged then discharged.

NOTE: If you need to familiarize yourself with the oscilloscope, before you start on this experiment, work through the exercise in Appendix A designed to familiarize you with this instrument. If you are doing this experiment using the computer and PASCO's DataStudio, no such review is necessary (a write up for this version of the lab is forthcoming).



Introduction and Theory

A Resistive-Capacitance, or RC circuit is an electronic circuit that is driven by a voltage or current source such as a battery or power supply. The simplest form of such a circuit is the “First Order” RC circuit consisting of one resistor and one capacitor. Along with the inductor (L) the resistor and the capacitor make up three basic linear analog components which, when put together in various combinations, exhibit behavior that is fundamental to much of analog electronics and, thus, have important applications. They are commonly used as passive filters.

Two fundamental types of passive filters are the high-pass filter and the low-pass filter. The high-pass filter presents less attenuation to high-frequency signals than low-frequency signals by passing a signal through a capacitor or a path to ground through an inductor. The low-pass filter presents less attenuation to low-frequency signals than high frequency signals by passing the signal through an inductor or by allowing a capacitor to provide a path to ground. These are two types of electronic circuits that allow wanted frequencies to pass through while blocking unwanted ones.

If a capacitor (C) is connected to a voltage source (V) charge will acquire on the plates. As the charge on the plates increases it becomes more difficult to add additional charge because of the increasing Coulomb force. This continues until the voltage across the plates equals that of the voltage source. At any time (t), the charge (Q) on the capacitor plates is given by

$$Q = CV$$

The rate at which the capacitor charges and discharges is dependent on the capacitor and resistor in the circuit. An important term in charging and discharging a capacitor is the RC time constant

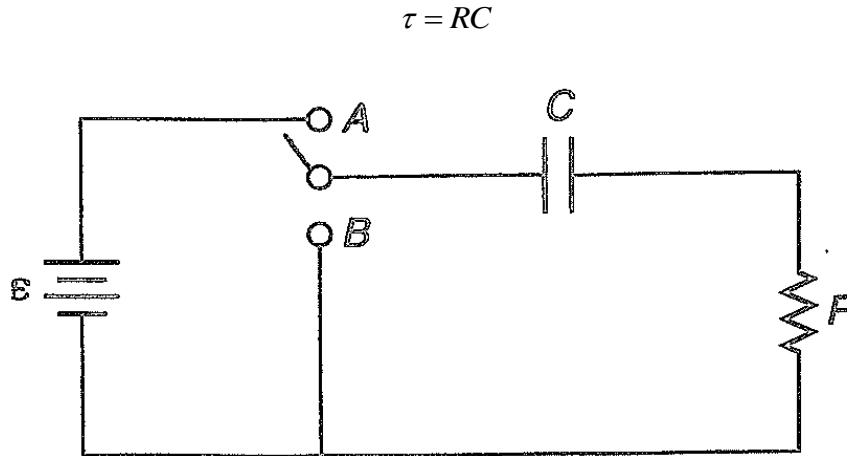


Figure 1.

Referring to the circuit shown in Figure 1, when the switch is in position **A**, the capacitor will charge. When charging a capacitor with a DC source, V_o , the voltage (V_c) and charge Q will increase over time. The voltage is characterized by the equation

$$V_C(t) = V_o(1 - e^{-t/RC}) = V_o(1 - e^{-t/\tau})$$

If $t = RC = \tau$, then the equation reduces to

$$V_C(t) = V_o(1 - e^{-t/\tau}) = V_o(1 - \frac{1}{e}) = 0.63V_o$$

So, the capacitor is 63% charged at $t = RC$. The time to fully charge the capacitor will be infinite. The capacitor will be 99.3% charged after five time constants.

When the switch in Figure 1 is at position **B**, the capacitor will discharge its energy through the resistor. When discharging a capacitor the voltage (V_c) and charge Q will decrease over time. The voltage is characterized by the equation:

$$V_C(t) = V_o e^{-t/RC} = V_o e^{-t/\tau}$$

If $t = RC = \tau$, then the equation reduces to:

$$V_C(t) = V_o e^{-t/\tau} = V_o \frac{1}{e} = 0.37V_o$$

So, the capacitor is 37% discharged at $t = RC$.

Since $Q = C V_c$, the amount of charge on capacitor while charging and discharging it is given by

Charging: $Q(t) = Q_o(1 - e^{-t/RC}) = Q_o(1 - e^{-t/\tau})$

Discharging: $Q(t) = Q_o e^{-t/RC} = Q_o e^{-t/\tau}$

For charging an initially uncharged capacitor or discharging an initially fully charged capacitor, the circuit current varies as

$$I = I_o e^{-t/\tau} = \frac{V_o}{R} e^{-t/\tau}$$

Laboratory #6 Report Sheet: RC Circuits

Experimenters: _____

Course: _____

Date: _____

Objective

The objective of this experiment is to use an RC circuit and the rate at which a capacitor charges and discharges, namely, the RC time constant, to determine its capacitance.

Equipment

DC Power Supply	1
Resistor Box	1
Capacitor (100 μ F)	1
2-Position Switch	1 (optional)
Data Studio w/ Voltage Sensor,	1
Lead Wires	5
Alligator Clips	5

Procedure

1. Set the resistor box for a time constant $\tau = RC \approx 1$ s. (e.g., if $C = 100$ μ F, then $R = 10$ k Ω .)
2. Short the capacitor by connecting the leads together to ensure that it is not charged.
3. Connect the circuit shown in Figure 1 with the switch at position **B**.
4. Open Data Studio and connect to the voltage sensor. Setting the sampling rate to 100 Hz will permit measurements of time constants greater than 0.1 s.
5. Connect the Data Studio voltage sensor across the capacitor.
6. Turn on the power supply and set the voltage not to exceed 8 V. (**Do not saturate the power supply voltage.**)
7. Start Data Studio to graph V_c vs. t .
8. Move the switch to position **A** to charge the capacitor.
9. When the voltage plateaus ($V_c \approx V_o$), move the switch to position **A** to discharge the capacitor.
10. Stop Data Studio when the capacitor is nearly fully discharged ($V_c \approx 0$), and you are satisfied with the resulting curves. (If not satisfied, repeat steps 8 and 9 until you are, or start a new data set by repeating steps 7–10.)
11. Highlight the voltage rise (charging) and fit with an “inverse exponential” fit to obtain the time constant. Print the fitted data noting the values used for the resistance and capacitance on the plot.
12. Highlight the voltage decline (discharging) and fit with a “natural exponential” fit to obtain the time constant. Print the fitted data noting the values used for the resistance and capacitance on the plot.

13. Change the value of the resistance on the resistance box by a factor of 2 to 10, and repeat the experimental steps 7–12.

Data and Data Analysis

Experiment 1

$$V_o = \underline{\hspace{2cm}}, \quad R = \underline{\hspace{2cm}}, \quad C = \underline{\hspace{2cm}}$$

$$\text{Theoretical } \tau = RC = \underline{\hspace{2cm}}$$

$$\text{Experimental } \tau \text{ (charging)} = \underline{\hspace{2cm}}, \quad \text{Experimental } \tau \text{ (discharging)} = \underline{\hspace{2cm}}$$

(Plots attached.)

Experiment 2

$$V_o = \underline{\hspace{2cm}}, \quad R = \underline{\hspace{2cm}}, \quad C = \underline{\hspace{2cm}}$$

$$\text{Theoretical } \tau = RC = \underline{\hspace{2cm}}$$

$$\text{Experimental } \tau \text{ (charging)} = \underline{\hspace{2cm}}, \quad \text{Experimental } \tau \text{ (discharging)} = \underline{\hspace{2cm}}$$

(Plots attached.)

Conclusion

Attach a typed Conclusion and Discussion section.

Questions:

For questions 1 and 2 below, assume an RC circuit as above with $V_o = 10 \text{ V}$, $C = 100 \text{ }\mu\text{F}$, and $R = 10 \text{ k}\Omega$. (Show your work.)

1. Assuming the capacitor is initially uncharged, what is the value of the voltage across the capacitor after 5 time constants? $\underline{\hspace{2cm}}$
2. With $V_C(t) = V_o e^{-t/RC} = V_o e^{-t/\tau}$, it mathematically takes an infinite time for the capacitor in an RC circuit to discharge completely. Practically, how many time constants does it take for the capacitor to discharge to less than 1% of its initial voltage? $\underline{\hspace{2cm}}$
3. What is the time constant of the circuit shown above? $\underline{\hspace{2cm}}$

Pre-Laboratory Exercise #7: Magnetic Force

Name: _____

Course: _____

Date: _____

1. An electron traveling horizontally enters a region where a uniform magnetic field is directed into the plane of the paper as shown. Which one of the following phrases most accurately describes the motion of the electron once it has entered the field?

- (a) upward and parabolic
- (b) upward and circular
- (c) downward and circular
- (d) upward, along a straight line
- (e) downward and parabolic

2. An electron is moving with a speed of 3.5×10^5 m/s when it encounters a magnetic field of 0.60 T. The direction of the magnetic field makes an angle of 60.0° with respect to the velocity of the electron. The magnitude of the magnetic force on the electron is _____. (Show your work.)

3. A 0.150-m wire oriented horizontally between the poles of an electromagnet carries a direct current of 12.5 A. The angle between the direction of the current and that of the magnetic field is 25.0° . If the magnetic field strength is 0.625 T, what is the magnitude and direction of the magnetic force on the wire between the poles? _____ (Show your work.)

NOTE: The Magnetic Force Lab, if it is performed, will be done using the Instruction Manual and Experiment Guide for the PASCO Scientific Model SF-8607 and SF-8608 Basic Current Balance and Current Balance Accessory. Hard copies are available in the drawers where lab forms are kept, and a soft copy version is appended as an appendix to this document.

Pre-Laboratory Exercise #8: Magnetic Induction

Name: _____

Course: _____

Date: _____

1. The magnetic flux through a surface is defined as $\Phi = BA\cos\theta$. At what angle is the magnetic flux (a) maximum and (b) minimum?

(a) _____

(b) _____

2. A 2-T uniform magnetic field makes an angle of 30° with the z axis. The magnetic flux through a 3 m^2 portion of the x-y plane is _____. Show your work.

3. Faraday's law states that an induced emf is proportional to the

- (a) rate of change of magnetic field.
- (b) rate of change of electric field.
- (c) rate of change of magnetic flux.
- (d) rate of change of electric flux.

4. In an experiment, two coaxial coils are used to investigate induction. A sinusoidal current is passed through the first coil. The induced emf in the second coil does not depend on the

- (a) frequency of the current.
- (b) number of turns in coil 2.
- (c) area of coil 2.
- (d) resistance of coil 2.
- (e) amplitude of the current in coil 1.

Laboratory 8—Magnetic Induction

Purpose

The purpose of this experiment is to understand how changing magnetic fields can produce electric currents. In doing so, we examine Lenz's Law and Faraday's Law.

Introduction and Theory

Magnetic flux is defined as the product of magnetic field lines and the area through which they pass. Of importance is that the total magnetic flux through a closed surface is zero. This implies that monopoles do not exist. The magnetic flux is dependent on the strength of the magnetic field, the size of the area through which they pass and the angle between the normal of the area and the magnetic field. We will investigate the dependence of flux on these variables and how a changing flux can induce currents in other coils.

One practical use for inductance is to detect the presence of cars at a stoplight. An inductive loop is a coil of wire that winds a certain number of turns. This coil is embedded in the road's surface and works by detecting a change of inductance. This change comes about when a large steel object, the car, is placed within the inductor's magnetic field and that changes the inductance, which is detected by a meter, which then sends a command to the light to switch from red to green after a short interval of time.

When electric current first starts flowing in a coil, the coil's tendency is to build up a magnetic field. While the field is building, the coil inhibits the flow of current. Once the magnetic field is built up, the current flows normally through the wire. When the switch is opened, and the circuit is broken, the magnetic field around the coil maintains an electric current until the magnetic field collapses. The inductor has a characteristic called capacity which is influenced by two factors:

- The number of coils
- The material that the coils are wrapped around (the core)

Putting iron in the core of an inductor gives it much more inductance than air or any other non-magnetic core would. There are devices that can measure the inductance of a coil, and the standard unit of measure is the **Henry**.

Magnetic flux is defined as the product of the magnetic field and the area through which they pass. The magnetic flux is dependent on the strength of the magnetic field, the size of the area through which they pass and the angle between the normal of the area and the magnetic field. Recall that the electric flux through any closed surface is proportional to the electric charge enclosed by the surface. There are no magnetic charges (monopoles), and the magnetic flux through any closed surface is zero. However, a changing magnetic flux will produce an emf in a conductor and cause a current to flow.

Magnetic flux through a surface is defined as $\Phi = BA \cos \theta$, where B is the magnetic field in tesla, A the area in m^2 and θ the angle between the area normal and the magnetic field. When θ is 90° the magnetic field is in the plane of the surface and $\Phi = 0$. When $\theta = 0^\circ$ or 180° the magnetic field is perpendicular to the surface and Φ is a maximum value BA .

Faraday's law states a changing magnetic field induces an electric field, this is summarized in the following equation, $\varepsilon = -\frac{\Delta\Phi}{\Delta t}$, where ε is the electromotive force, and Φ is the magnetic flux. It states, if we have a magnetic flux which changes in time, it induces an emf. If that emf is induced in a material capable of carrying a current, a current will result. The sense of the current will be such that it produces a magnetic field that opposes the changing magnetic flux. This is *Lenz's law*:

The induced current in a loop is in the direction that creates a magnetic field that opposes the change in magnetic flux through the area enclosed by the loop.

Again, Faraday's law of induction is

$$\varepsilon = -N_2 \frac{\Delta\Phi}{\Delta t} = -N_2 \frac{\Delta(BA \cos \theta)}{\Delta t} = -N_2 A \cos \theta \frac{\Delta B}{\Delta t}$$

where we assume a secondary coil (coil 2) of N_2 turns. To generate our magnetic field we shall use a 200-turn Helmholtz coil, coil 1. Along the axis perpendicular to the loop the magnitude of the magnetic field is

$$B = \frac{\mu_o N_1 I_1 R_1^2}{2(x^2 + R_1^2)^{3/2}}$$

where $\mu_o = 4\pi \times 10^{-7} \frac{T \cdot m}{A}$ is the permeability of free space, I is the current, N is the number turns and R is the radius of the coil, and x is the distance perpendicular along the coil axis. A signal generator will provide a sinusoidal current to the primary coil to produce B . Hence,

$$B = B_o \sin(2\pi ft), \text{ where } B_o = \frac{\mu_o N_1 I_{1\max} R_1^2}{2(x^2 + R_1^2)^{3/2}}$$

And...

$$\varepsilon = -N_2 A \cos \theta \frac{\Delta B}{\Delta t} = -2\pi f N_2 B_o A \cos \theta \cos(2\pi ft)$$

Laboratory #8 Report Sheet: Magnetic Induction

Experimenters: _____

Course: _____

Date: _____

Purpose

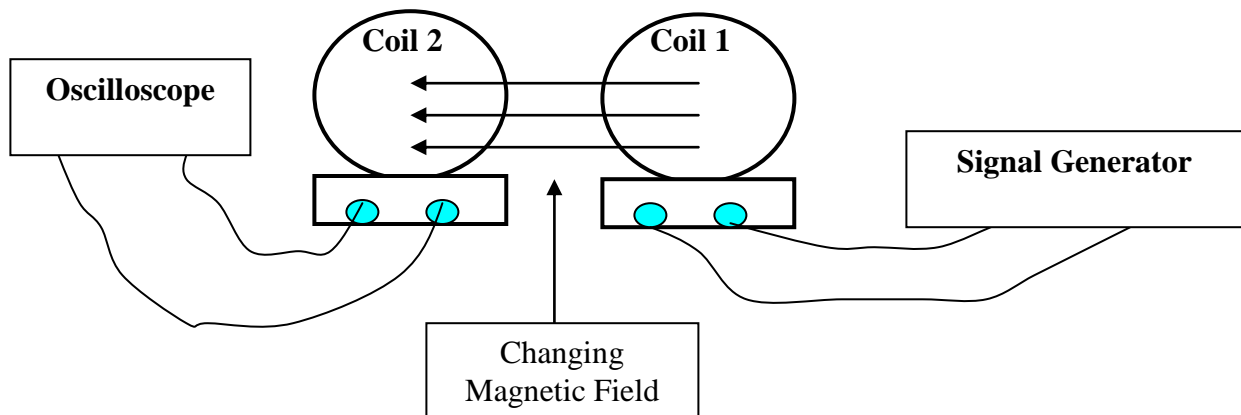
The purpose of this experiment is to examine Faraday's law of induction which states that a changing magnetic flux produces an emf and electric current in a conductor.

Equipment

Oscilloscope	1
Function Generator	1
Helmholtz Coils	1 pair, with base
Coaxial Cables	1 set

Procedure

Connect the experiment as shown below...



Data

Calculate the magnetic field in coil 1 and coil 2 when it is 10 cm from coil 1 and both coils are parallel to each other. Use Ohm's law, $V = IR$ to obtain the current. (Show work.)

$V_1 =$ _____; $R_1 =$ _____; $I_1 =$ _____

$B_{\text{calculated}_1} =$ _____ tesla $B_{\text{calculated}_2} =$ _____ tesla

Complete Table 1 Below (For ease, you may record peak-to-peak voltage.)

Angle degrees	Distance between Coils	Frequency Coil 1 Hz	Voltage 1 Volts	Voltage 2 Volts	V_2/V_1
0	10 cm	200 Hz			
10	10 cm	200 Hz			
20	10 cm	200 Hz			
30	10 cm	200 Hz			
40	10 cm	200 Hz			
50	10 cm	200 Hz			
60	10 cm	200 Hz			
70	10 cm	200 Hz			
80	10 cm	200 Hz			
90	10 cm	200 Hz			
100	10 cm	200 Hz			
110	10 cm	200 Hz			
120	10 cm	200 Hz			
130	10 cm	200 Hz			
140	10 cm	200 Hz			
150	10 cm	200 Hz			
160	10 cm	200 Hz			
170	10 cm	200 Hz			
180	10 cm	200 Hz			

Make a graph of the induced voltage (V_2) versus angle

- a. What is the shape of the induced voltage in coil 2 versus angle?
- b. Is this what you expected and why?
- c. What is observed of the frequency in coil 2? How does it compare to the frequency in coil 1? What does this tell you?
- d. At 0° what is the peak voltage in coil 2? What did you expect for this value?

Complete Table 2 Below (For ease, you may record peak-to-peak voltage.)

Angle degrees	Distance between Coils	Frequency Coil 1 Hz	Voltage 1 Volts	Voltage 2 Volts	V_2/V_1
0	3cm	150			
0	4 cm	150			
0	6 cm	150			
0	8 cm	150			
0	10 cm	150			
0	12 cm	150			
0	14 cm	150			
0	16 cm	150			
0	18 cm	150			
0	20 cm	150			

Make a graph of the induced voltage versus distance

- a. What is the shape of the induced voltage in coil 2 versus distance?
- b. Is this what you expected and why?
- c. What did you observe about the emf values based upon the distance between the coils?
- d. What is observed of the frequency in coil 2? How does it compare to the frequency in coil 1? What does this tell you?

Things to Consider

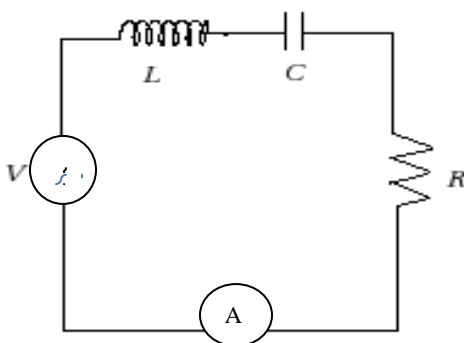
- 1. Do you think it is possible to measure the earth's magnetic field in a given direction by looking at the induced emf in a coil? If so, how would you construct the experiment and determine its value?
- 2. Can you use coil 2 to determine the presence of other signals in the vicinity? How would you demonstrate this and which frequencies if any did you find?
- 3. How do you think the number of turns affects the outcome of the experiment?

Pre-Laboratory Exercise #9: RLC Circuits

Name: _____

Course: _____

Date: _____



Consider the RLC circuit shown above with a peak voltage of 240 V, $f = 60$ Hz, $R = 100$ k Ω , $L = 0.5$ mH, $C = 200$ μ F. (Show your work.)

1. What is the impedance of the circuit? _____
2. What is the value of the current read by the ammeter? _____
3. What is the (linear) resonant frequency of the circuit? _____

Laboratory 9—RLC Circuits

Purpose

The purpose of this experiment is to study currents and voltages in RLC circuits. We will measure the response of the voltage across a resistor (V_r) as a function of a voltage applied at different frequencies.

Introduction & Theory

When an inductor L , a resistor R and a capacitor C are connected in series, the alternating current I present in the circuit depends on the frequency of the driving voltage E . This type of circuit is used extensively in electronic devices, particularly radios and televisions.

These circuits are used in a number of electronics applications including the tuning of analog radios and televisions. Adjustable tuning is usually achieved by using a parallel plate variable capacitor which enables the value of C to be changed, which enables the receiver to tune to stations of different frequencies. The inductor comes with an adjustable core which enables the inductance, L , to be changed. The core is made of a high permeability material that effectively increases inductance and is threaded so that it can be screwed in or out of the inductor winding as needed.

Filters are another common use of RLC circuits. In a filtering application, the resistor R becomes the load that the filter is working into. The damping factor value is selected based on the desired bandwidth of the filter. A wider bandwidth uses a larger damping factor and vice versa. The three components of the circuit give three degrees of freedom to the designer of the circuit to enable the desired outcome to be met. Two of the components are required to set the bandwidth and the resonant frequency; the third can be adjusted in such a way so as to scale each of the three components to convenient values. In another setting, R may be predetermined by the circuitry within which this circuit is found and which will use this last degree of freedom.

Other common uses of RLC circuits include the use of the circuit as an oscillator whereby the attenuation (or damping factor) is made as small as possible. This can be adjusted by making the R be as small as possible for series circuits and as large as possible for parallel circuits. Other uses also include making the circuit a voltage multiplier or a pulse discharge circuit.

An important property in RLC circuits is **resonance**, which is the ability of the circuit to resonate at a specific frequency, called the resonant frequency. Resonance in the circuit happens because energy is stored in two different ways: as an electric field as the capacitor is charged, and as a magnetic field as the current flows through the inductor. Energy can be transferred from one to the other and back again in an oscillatory mode, much like the mass at the end of a spring oscillates back and forth between one extreme and the other. The mathematics describing both are identical in form. Whereas friction in the spring-mass system will eventually bring the system to a halt, the resistance in the RLC circuit will diminish the oscillation over time. Like a vibrator that can keep the mass on a spring oscillating indefinitely, the driving AC power source will keep the circuit resonating indefinitely.

The resonant frequency is defined as the frequency at which the impedance of the circuit is at a minimum. In the series LRC circuit that we will be studying, the impedance reaches a minimum when resonance is achieved (in parallel LRC circuits this happens when the impedance reaches a maximum). The resonant frequency is reached because the inductor and capacitor are equal but of opposite sign, so they cancel out.

The AC current of a RLC circuit connected in series depends on the voltage and impedance.

$$I = \frac{V}{Z}$$

Impedance is the AC circuit equivalent of resistance. This describes not only the amplitude of voltages and currents but also the relative phases. The impedance is defined mathematically as:

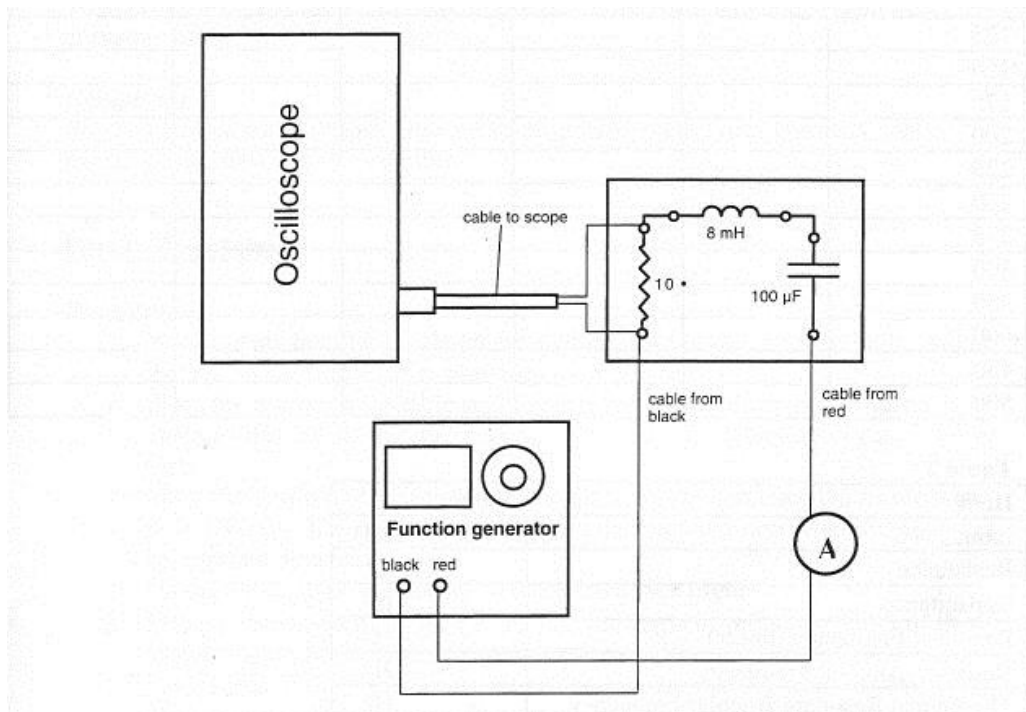
$$Z = \sqrt{(X_L - X_C)^2 + R^2}$$

Where the inductive reactance is, $X_L = \omega L$ the capacitance reactance is $X_C = \frac{1}{\omega C}$, and R is the resistance and the angular frequency is $\omega = 2\pi f$ where f is the linear frequency. The current will have a maximum value at resonance when $X_L = X_C$ this condition defines the resonant frequency at $\omega_{res} = \frac{1}{\sqrt{LC}}$. For this condition the impedance $Z = R$ and has a minimum value, which results in the current having a maximum value.

Note: This lab has several variations which are included below. The standard report sheet with its procedure is also included. The professor may decide to do one or the other (or a combination of both). In addition an electronic workbench activity is added.

Suggested Procedure

1. Set up the circuit as shown below. The function generator will apply the voltage to the circuit at different frequencies. The oscilloscope will measure the voltage across the resistor. Record the data in the table
2. Plot a graph of V_r vs. linear frequency (f)
3. Determine the inductive reactance, Capacitive reactance, impedance and amplitude of the current through the resistor and plot X_L vs. frequency (f), X_C vs. f , and Z vs. f .
4. Refer to the “Analyzing the data” section on the image below.



Analyzing the data

1. From the graph find the linear resonant frequency, f_{res} .
2. Using the resonant frequency f_{res} , calculate the resonant angular frequency, ω_{res} and record the value in the Table 2.
3. Calculate the theoretical resonant angular frequency using the values of the inductance and capacitance.
4. Compare the theoretical resonant frequency to your measured resonant frequency.

Results

Complete Table 1:

[illegible]

Complete Table 2 Below:

Parameter Name	Parameter Value
Inductance	
Resistance	
Capacitance	
Resonant Frequency (linear)	
Resonant Angular Frequency	
Theoretical Resonant Angular Frequency	

Conclusions & Questions

1. How does the measured value for the resonant angular frequency compare to the theoretical value for the resonant angular frequency?
2. Is the plot of impedance current versus frequency symmetrical about the resonant frequency? Explain.

At resonance, the reactances of the inductor and the capacitor cancel each other out so that the impedance (Z) is equal to just the resistance R . Calculate the resistance of the circuit by using the amplitude of the current at resonance in the equation $R = V/I$. Is the resistance equal to that used in the circuit? Why or why not?

Optional Electronic Workbench / MultiSim Extension

Purpose



The purpose of this activity is study currents and voltages in RLC circuits. We will measure the response of the voltage across a resistor (V_r) as a function of a voltage applied at different frequencies using Multisim.





Equipment

Multisim software

Procedure

Open the Multisim program. Click on PLACE, then click on COMPONENT. Click on the drop down bar below GROUP and select BASIC. Select RESISTOR and under COMPONENT, select the value resistor then click ok. Select CAPACITOR, select the value, then click ok. Select INDUCTOR, select the value, then click ok. Click on the drop down bar below GROUP, select SOURCES, then POWER_SOURCES, then GROUND, then click on ok. Go to the same drop down bar, select INDICATORS, then select AMMETER, the select AMMETER_H then click ok. Then close the SELECT A COMPONENT tab.

Go to the right side of the program. Run the mouse over the icons and select FUNCTION GENERATOR . Drag it closer to the other components and the left click. Go back to the right side of the program and select OSCILLOSCOPE . Drag it closer to the other components and left click. Click on the edge of the components and use the wire to connect them. The circuit should look like figure 1 below. Ensure that the positive terminal of the function generator goes to the positive terminal of the ammeter. Check the schematic in the figure 1 below to ensure that the terminal match your schematic.

Double click on the oscilloscope. Then click run  or . Then click stop  or . Pull the green vertical line that is on the left of the graph to the crest of the sine wave on the graph (It will change color to yellow). Then pull the red vertical line to the trough (it will change to blue) and record your results given by the yellow vertical line. Your results should look like figure 2 below.

Double click on the function generator and change the frequency. Run and stop the experiment and record your results.

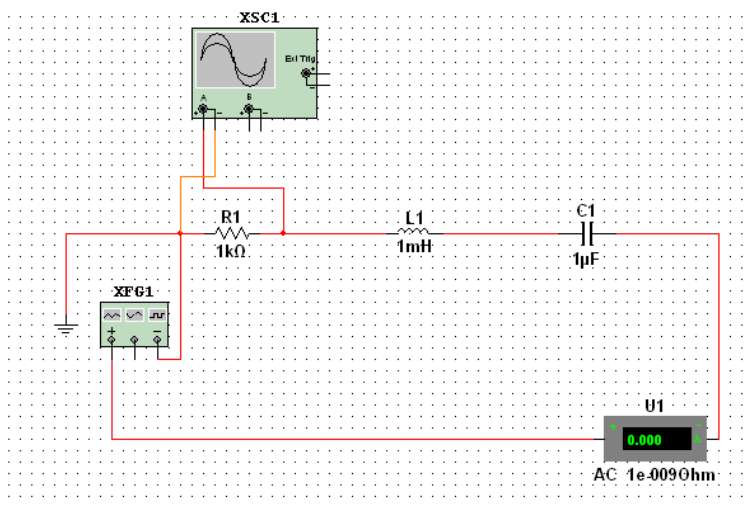


Figure 1: RLC Circuit.

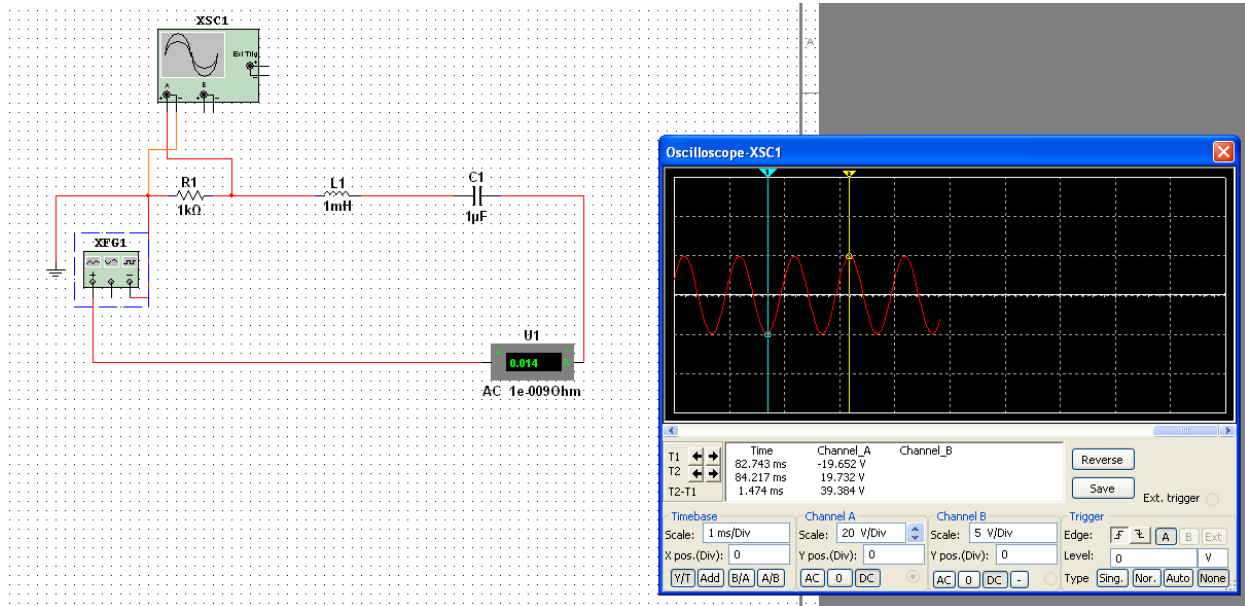


Figure 2: Results should look like this

Results

Complete Table 1:

Linear Frequency	V_r (V)	$X_L = 2\pi fL$ (Ω)	$X_C = \frac{1}{2\pi fC}$ (Ω)	Z (Ω)	$I = \frac{V_R}{Z}$ (Ω)

Conclusion

Please include a conclusion statement with your write-up.

Laboratory #9 Report Sheet: RLC Circuits

Experimenters: _____

Course: _____

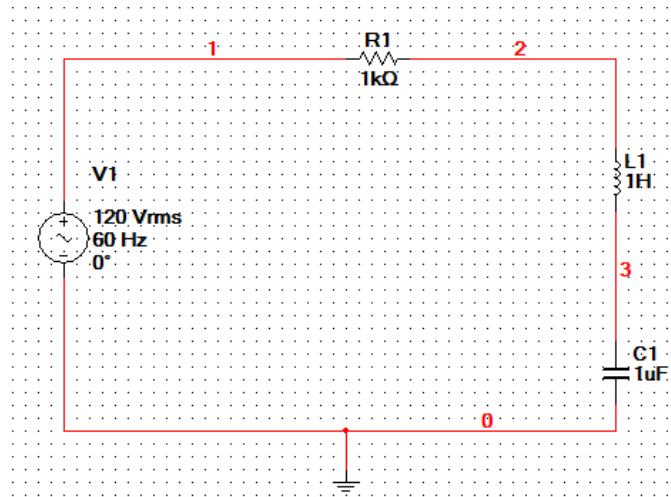
Date: _____

Purpose

The purpose of this activity is to study the currents and voltages. We will measure the response of the voltage across a resistor (V_r) as a function of a voltage applied at different frequencies.

Introduction and Theory

Schematic



f = adjustable frequency

$$\omega = 2\pi f$$

V = voltage

I = current

Overall resistance:

$$Z = \frac{V}{I} \Leftrightarrow I = \frac{V}{Z}, Z = \sqrt{R^2 + (X_L - X_C)^2} \text{ where } X_L = \omega * L \text{ and } X_C = \frac{1}{\omega * C}$$

The smallest Z , occurs when $X_L = X_C$; Resonance condition... $\omega_0 * L = \frac{1}{\omega_0 * C} \Rightarrow \omega_0^2 = \frac{1}{L * C}$

$$\omega_0 = \frac{1}{\sqrt{L * C}}, \therefore f_0 = \frac{1}{2\pi\sqrt{L * C}} \approx 3600\text{Hz}$$

$$R = \underline{\hspace{1cm}}$$

$$L = 1.92\text{mH} = 1.92 * 10^{-3} H$$

$$C = 1\mu F = 1 * 10^{-6} F$$

(a) Calculate f_0 (theoretically)

(b) Determine experimentally the value of f_0 (experimentally).



Power or $(amplitude)^2$

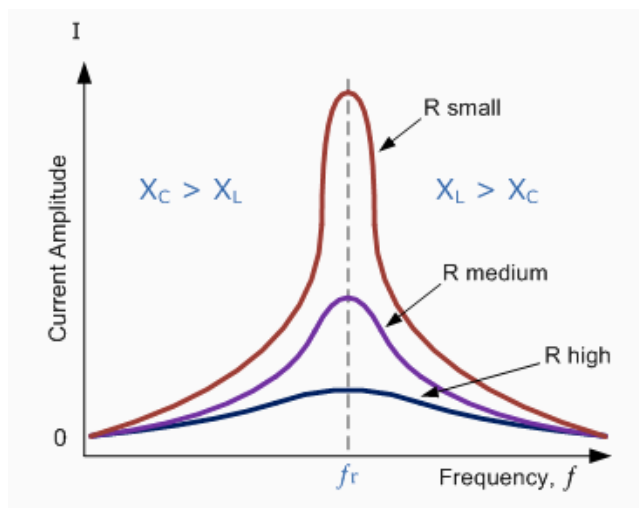
$$P_{avg} = \frac{1}{2} (amplitude)^2 = I_{rms}^2 R \text{ or } \frac{V_{rms}^2}{R} \Rightarrow I_{rms} = \frac{1}{\sqrt{2}} I_0, V_{rms} = \frac{1}{\sqrt{2}} V_0$$

$$V_{rms} = \frac{1}{\sqrt{2}} \left(\frac{1}{2} V_{pp} \right)$$

$$V_{rms} = I_{rms} R$$

Oscilloscope reads V_0 , AC meter reads I_{rms} , V_{rms}

Q or Quality of circuit



$$Q = \frac{2\pi f_0 L}{R}$$
$$\therefore Q = \frac{\omega_0 L}{R}$$

Equipment

The following components can be used as is or substituted by PASCO's AC/DC Electronics Laboratory

System	
Oscilloscope	1
Function Generator	1
Inductors	2
Capacitor	1
Resistor	1

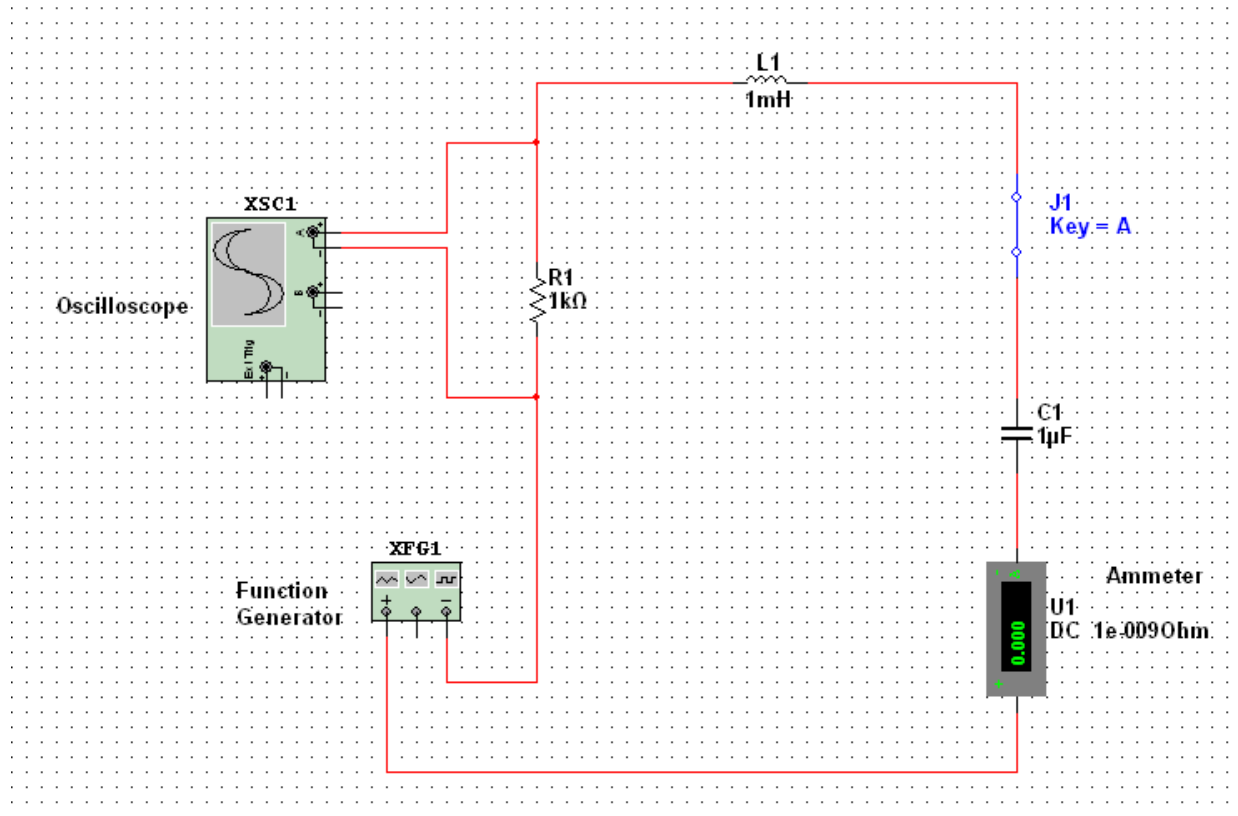
Procedure

Setup the circuit as shown below. The function generator will apply the voltage to the circuit at different frequencies. The oscilloscope will measure the voltage across the resistor. Record the data in the table.

Plot the graph of V_r vs. linear frequency (f)

Determine the inductive reactance, capacitive reactance, impedance and amplitude of the current through the resistor and plot X_L , X_C and Z vs frequency (f)

Refer to the "Analyzing the data" section on the image below.



RLC Circuit

Analyzing the data

From the graph find the linear resonant frequency, f_{res}

Using the resonant frequency f_{res} , calculate the resonant angular frequency, ω_{res} and record the value in the Table 2

Calculate the theoretical resonant angular frequency using the values of the inductance and capacitance.

Compare the theoretical resonant frequency to your measured resonant frequency

Results

Complete Table 1:

Linear Frequency	V_r (V)	$X_L = 2\pi fL$ (Ω)	$X_C = \frac{1}{2\pi fC}$ (Ω)	Z (Ω)	$I = \frac{V_R}{Z}$ (Ω)

Complete Table 2 Below:

ITEM	VALUE
Inductance	
Resistance	
Capacitance	
Resonant Frequency (linear)	
Resonant Angular Frequency	
Theoretical Resonant Angular Frequency	

Conclusion & Questions

How does the measured value for the resonant angular frequency compare to the theoretical value for the resonant angular frequency?

Is the plot of impedance current versus frequency symmetrical about the resonant frequency? Explain.

At resonance, the reactances of the inductor and the capacitor cancel each other out so that the impedance (Z) is equal to just the resistance R . Calculate the resistance of the circuit by using the amplitude of the current at resonance in the equation $R=V/I$. Is the resistance equal to the used in the circuit? Why not?

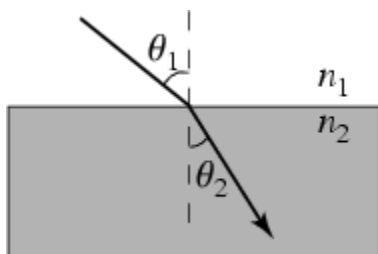
Pre-Laboratory Exercise #10: Reflection and Refraction of Laser Light

Name: _____

Course: _____

Date: _____

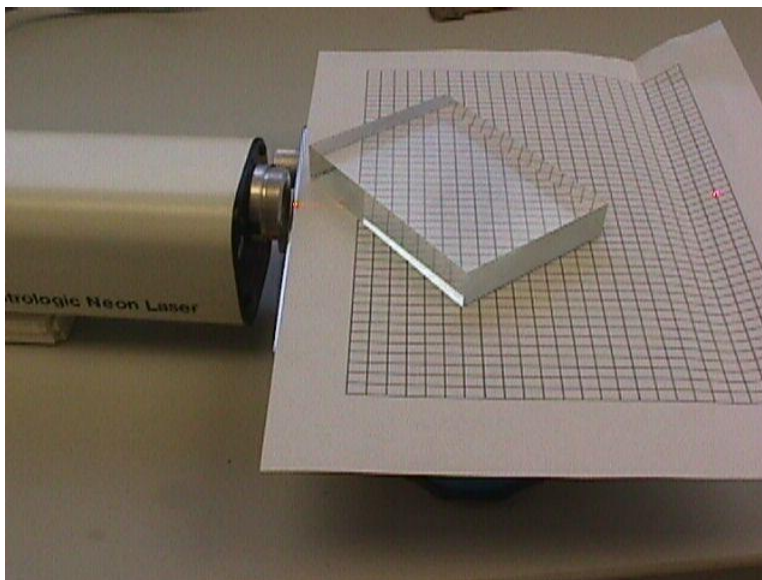
1. Light refracts when it travels from one medium to another. Explain why? What principle explains this behavior?
2. Given that the speed of light in a given medium is 2.3×10^8 m/s. Find the index of refraction, n , for that medium.



For questions 3 - 5, consider the figure given above in which light ($f_1 = 5.5 \times 10^{14}$ Hz) travels from medium 1 to medium 2. The index of refraction for medium one and two are 1.2 and 1.6, respectively. The angle of incidence θ_1 is 68° .

3. What is the frequency in medium 2?
4. What is the velocity of light in medium 2?
5. Find the angle of refraction, θ_2 ? (Show work.)

Laboratory 10—Reflection and Refraction of Laser Light



Purpose

The purpose of this laboratory exercise is to study the nature of reflection and refraction of laser light and find the index of refraction of the material used.

Introduction

When a light beam falls on a surface, both reflection from the surface and refraction into the substance occurs. Refraction is the bending of light as it passes from one substance to another. As light passes from a less dense to a more dense material it bends towards the perpendicular to the plane of the surface of the material. Conversely, light entering a less dense material will bend away from the perpendicular to the plane of the surface. The amount of bending which occurs depends both on the wavelength of the light and the type of material through which the light is propagating. A property of the material related to the amount of refractive bending is called the index of refraction of the material. The index of refraction of a material is usually quoted with respect to vacuum, where the vacuum is defined to have an index of refraction of one. The index of refraction of air is almost that of a vacuum, so light traveling in air can be considered to be in a vacuum. (This is a good approximation to an accuracy of three significant figures).

On the next page is a table of the index of refraction for a number of everyday items. This list is composed from lists that appear on several websites such as <http://hyperphysics.phy-astr.gsu.edu/hbase/tables/indrf.html> and the interactive website <http://interactagram.com/physics/optics/refraction/>, which provides a fairly detailed description of the phenomenon of refraction.

Index of Refraction of Selected Materials

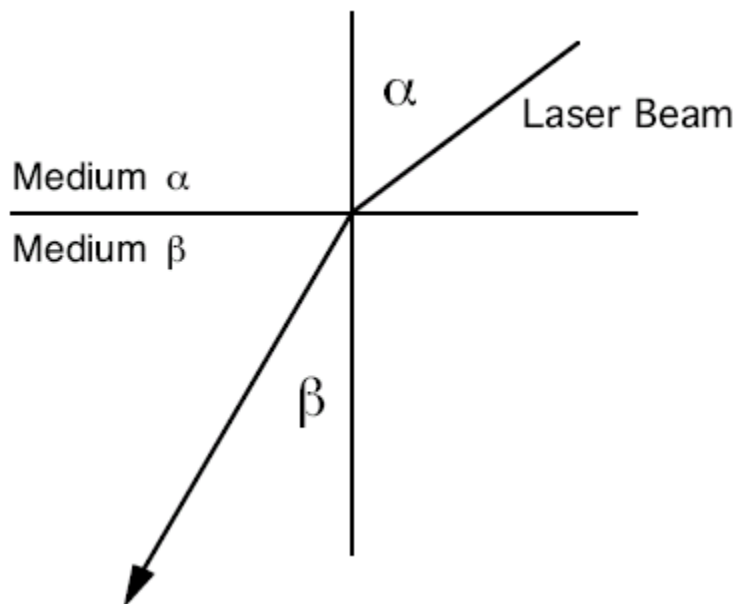
Material	Index	Material	Index
Vacuum	1.00000	Rock Salt	1.544
Water (gas)	1.000261	Sodium Chloride	1.544
Argon	1.000281	Quartz	1.544
Air at STP	1.0002926	Amethyst	1.544
Nitrogen (liq)	1.2053	Amber	1.546
Alcohol	1.329	Polystyrene	1.55-1.59
Ice	1.309	Emerald, Synth flux	1.561
Water 100°C	1.31819	Emerald, Synth hydro	1.568
Methanol	1.329	Flint glasses	1.57-1.75
Water 35°C (Room temp)	1.33157	Glass, Flint, Light	1.58038
Water 20°C	1.33335	Styrofoam	1.595
Teflon	1.35	Topaz, Blue	1.610
Acetone	1.36	Turquoise	1.610
Ethanol	1.36	Mercury (liquid)	1.62
Ethyl Alcohol	1.36	Topaz	1.620
Sugar solution (30%)	1.38	Topaz, Pink	1.620
Fluorite	1.433	Topaz, Yellow	1.620
Aluminum	1.44	Topaz, White	1.630
Opal	1.450	Glass, Flint, Medium	1.62725
Quartz, Fused	1.45843	Carbon disulfide	1.63
Plastic	1.460	Asphalt	1.635
Turpentine	1.472	Glass, Flint, Heavy	1.65548
Glycerine	1.473	Glass, Flint, Dense	1.66
Onyx	1.486	Olivine	1.670
Glass, Albite	1.4890	Methylene iodide	1.74
Sugar solution (80%)	1.49	Ruby	1.760
Ulexite	1.490	Sapphire	1.760 – 1.77
Plexiglas	1.50	Rare earth flint	1.7-1.84
Dolomite	1.503	Glass, Flint, Lanthanum	1.80
Gaylussite	1.517	Pyrite	1.810
Glass	1.51714	Lanthanum flint	1.82-1.98
Rubber, Natural	1.5191	Glass, Flint, Heaviest	1.89
Crown glasses	1.52-1.62	Sulphur	1.960
Typical crown glass	1.52	Crystal	2.00
Nylon	1.53	Arsenic trisulfide glass	2.04
Thomsonite	1.530	Zirconia, Cubic	2.170
Sodium chloride	1.54	Diamond	2.417

Theory

The defining equation for the index of refraction between any two materials is:

$$n_a \sin \alpha = n_b \sin \beta$$

where α is the bending angle with respect to the external medium, β is the bending angle with respect to the internal medium, n_α is the index of refraction of the external medium, and n_β is the index of refraction of the internal medium.



For the case where the medium α is air, then n_α is nearly one and we can rearrange the above equation to solve for the index of refraction of the material as:

$$n = \frac{\sin \alpha}{\sin \beta} \quad (\text{where } n \equiv n_\beta)$$

We will use a red laser beam as a source for the light ray (a laser generates a coherent, monochromatic light beam) with which to find the index of refraction of a slab of transparent material. This value for the index of refraction is valid only for photons that have the same wavelength as those from the laser.

Equipment

Laser	1
Glass block	1
Protractor or circular optics table	1

Procedure:

1. Use the materials listed and the above equation to determine the index of refraction of the glass block. A good procedure is to lay the block flat on a piece of paper and shine the laser light through the edge at a sufficiently large angle. Make a mark on the paper where the light enters and leaves the block. Construct perpendicular lines to the face of the edge to be used for measuring the appropriate angles.

2. What are the units of the index of refraction?
3. What are some sources of error?
4. Do you have enough information to determine the type of material the block is made of (assuming the table above was not provided)? Why or why not?
5. Round off your final answer correctly with respect to the amount of error.
6. Write up your report in the usual manner, remembering to answer all questions.

Bonus 1: Calculate the value of the speed of light inside the object used for refraction.

Bonus 2: Given that the wavelength of the helium-neon laser light is 632.8 nm, what material is the object used for refraction made of?

Extensions: Because of the brief nature of this lab, it is likely that your instructor may include some additional steps to provide more opportunity to explore the reflection and refraction of light. These steps may include (but are not limited to):

- Using the table provided in the Introduction, and the physical appearance of the object used to determine the index of refraction, identify the material out of which your block was made of.
- Repeat the experiment, but also trace the reflected beam as well as the refracted beam. Measure the reflected beam's angle to the normal along with the incoming beam's angle relative to the normal. What do you notice?
- Repeat the experiment with two or three other substances, to include a plastic container filled with water, a slab of glass, or anything else we may find in the storage room.
- Repeat the experiment with a green laser instead of a red one. Try to keep the orientation identical to that of the red laser (or better yet, shine them side by side). Are they reflected differently? Do they refract differently? What is the index of refraction as determined by the green laser and how does it compare with that determined by the red laser?

Laboratory 11—Laser with Diffraction Grating

(Adapted from Halliday / Resnick / Walker *Probe ware Lab Manual*, 6th Ed., pp. 182-183, © 2003 John Wiley & Sons, Inc.)

Purpose

The purpose of this experiment is to investigate the optical properties diffraction gratings using a laser.

Safety Note

Do not stare into the aperture (opening where the light comes out) of a laser at any time! Exposure to the laser light could result in permanent eye damage.

Introduction & Theory

When monochromatic light from a distant source such as a laser passes through a narrow slit then falls on a viewing screen, the light produces on the screen a diffraction pattern. This pattern consists of a broad and intense (very bright) central maximum and a number of narrower and less intense maxima (secondary maxima). Minima lie between the maxima. A Light Sensor measures the intensity of this pattern; the Rotary Motion Sensor mounted on the Linear Translator measures the relative positions of the maxima in the pattern.

The diffraction pattern for a single slit is similar to the pattern created by a double slit, but the central maxima is measurably brighter than the maxima on either side. Analysis of wave diagrams for light of wavelength λ passing through a single slit with width “ a ” gives the following general equation: $a \sin \theta = m \lambda$ where θ is the angle of the first dark fringe on either side of the central maxima. The dark fringes can be located with the general equation for $m = 1, 2, 3 \dots$ relating wavelength (λ), the number of fringes (m), and the slit width (a).

Analysis of wave diagrams for light of wavelength λ passing through a double slit with slit spacing “ d ” gives the following formula: $d \sin \theta = m \lambda$. The bright fringes can be located with this equation.

Equipment

Optical Bench	1
Diode Laser	1
Single Slit and Multiple Slit accessories	1 each
Lens mount and screen	1 each
Transmission gratings, 200, 300, 600, 13,400 lines/mm	1 each

Procedure

1. The apparatus should already be set up for you. Make sure the lens bracket and laser are close to one end of the bench with the white screen near the other.

2. Rotate the SLIT SET disk, the Single Slit one, on the Slit Accessory until a slit pattern is in line with the laser beam. Use the 0.04 mm slit. Use the adjustment screws on the back of the Diode Laser to adjust the beam if necessary.
3. Examine the diffraction pattern on the white screen. If the pattern is not horizontal, loosen the thumbscrew on the Slit Accessory. Slowly rotate the Slit Accessory until the laser beam is centered on the slit pattern you want and the diffraction pattern is horizontal on the white screen on the Aperture Bracket, parallel to the ruled paper attached to the screen. Tighten the thumbscrew on the Slit Accessory to hold it in place.
4. Read off the position of the dark fringes, in mm, on either side of the central maximum. For better accuracy, a set of Vernier calipers can be used to measure the distances between the minima. If you use the ruler, to get the distance between the two, subtract the smaller number from the larger, and write this in the Data Table, first space. Repeat for the second and third sets of slits
5. Take each of the values you wrote in #4 and divide by two to get the distance of the minima from the central maxima and record these in the next column
Using the parameters for a and λ on the Slit Accessory and laser respectively, plug these values into the equation, along with $m=1$ to solve for $\sin\theta$; record in data table. Repeat for $m=2$ and $m=3$
6. Refer to the Board to find out how to calculate the theoretical value for d .
7. Repeat 2 to 5 for the multiple slit case (you will only need to measure the distances, and compare these to the corresponding distances for the single slit case) and fill in that data table.
8. For the first table, compare your measured d 's with your calculated ones using the % difference formula:

$$\%diff = \left| \frac{(\lambda_{calc} - \lambda_{given})}{\lambda_{given}} \right| \times 100\%$$

Finally, in the back corner of the room are several lasers with transmission gratings. Place each available grating, one at a time, between the laser and wall and note the pattern of dots on the wall. How does the pattern change with each different grating? You do not have to take measurements, just a qualitative observation should be sufficient. Record your response in the Discussion section of your lab report.

Laboratory 12—Concave and Convex Lenses

(Adapted from: Jerry Wilson, *Physics Laboratory Experiments*, 4th Ed., pp. 471-475, © 1994 Houghton Mifflin Company)

Purpose

The purpose of this experiment is to investigate the optical properties of convex and concave lenses.

Introduction

Mirrors and lenses are familiar objects that we use on a daily basis. The most commonly used mirror is what is called a plane mirror, which is used for cosmetic applications. Spherical mirrors have many common applications, such as security monitoring of store aisles and merchandise, and concave spherical mirrors are used as flashlight reflectors. Mirrors reflect light, while lenses transmit light. Spherical lenses are used to converge and focus light (convex spherical lenses) and to diverge light (concave spherical lenses).

This experiment will focus on spherical lenses of two types—convex and concave. Convex lenses are sometimes called converging lenses because rays parallel to the principle axis converge at the focal point. A concave lens is called a diverging lens because rays parallel to the perpendicular axis appear to diverge from the focal point.

Theory

If the image is formed on the side of the lens opposite the object, it is real and can be observed on a screen. However, if the image is on the same side of the lens as the object, it is a virtual image and cannot be seen on the screen. Analytically, the thin-lens equation and magnification factor are used with the sign convention similar to that in the following table. These equations apply only to thin lenses. The focal length of a lens is given by the lens maker's equation:

$$\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

Where n is the index of refraction for the lens material and the R 's are taken as positive for convex surfaces. Lenses used in the laboratory are made from glass, which has an n between 1.5 and 1.7. As an example, for glass with $n = 1.5$ and symmetrical converging lenses, ($R_1 = R$ and $R_2 = R$), the equation yields $f = R$ (for f to be equal to $R/2$ for a symmetrical lens requires $n = 2$, which is greater than the index of refraction of glass). The focal length of a lens depends on the R -values in general, which can be different, as well as n .

Quantity	Conditions	Sign
Focal Length, f	Convex Lens	+
	Concave Lens	-
Object distance, d_o	Usually (always in this experiment), although there are some cases of lens combinations where d_o may be negative when an image is used as an object.	+
Image distance, d_i	Image real	+
	Image virtual	-
Magnification, M	Image upright	+
	Image inverted	-

Equipment

Concave and Convex Lenses (one of each)	1
Convex Lens (focal length longer than 1 st convex lens)	1
Meter stick optical bench (white cardboard can serve as the screen) or precision (PASCO) bench with lens holder and white screen	1
Light Source: candle and candleholder, or electric light source with object arrow.	1

Procedure

Convex Lenses

1. Sketch a ray diagram for a convex lens with the object at its focal point. The image is formed at infinity.
2. using the lens equation, determine the image characteristics for an object at infinity.
3. Experimentally determine the focal length of the lens. (The lens may be placed in a lens holder and mounted on a meter stick.)
4. Solve cases 1 to 4.

Case 1: $d_o > R$

Sketch a ray diagram for an object at a distance slightly beyond R (i.e., $d_o > R$) and note the image characteristics.

- a. Set this situation up on the optical bench, with the object placed several centimeters beyond the radius of curvature (known from f determination with $R=2f$). Measure the object distance d_o , and record it. It is usually convenient the lens manually and adjust the object distance by moving the lens rather than the object light source. Move the screen along the side of the optical bench until an image is observed on the screen. This is best observed in a darkened room. The lens may have to be turned slightly to direct the rays toward the screen.
- b. Estimate the magnification factor M and measure and record the image distance d_i .
- c. Using the lens equation, compute the image distance and the magnification factor.
- d. Compare the computed value of d_i with the experimental value by computing the percent difference

Case 2: $d_o = R$. Repeat the procedure for this case.

Case 3: $f < d_o < R$. Repeat the procedure for this case.

Case 4: $d_o < f$. Repeat the procedure for this case.

It is initially instructive to move the lens continuously toward the object light source (decreasing d_o) from a $d_o > 2f$ and to observe the image on the screen, which also must be moved continuously to obtain a sharp image. In particular, notice the change in the size of the image as d_o approaches f .

Concave Lens

5. Sketch ray diagrams for objects at (1) $d_o > R$, (2) $f < d_o < R$, and (3) $d_o < f$, and draw conclusions about the characteristics of the image of a convex lens. Experimentally verify that the image of a convex lens is virtual (i.e., try to locate the image on the screen).
6. It is possible to determine the focal length of a concave lens experimentally by placing it in the contact lens combination has a focal length f_c given by

$$\frac{1}{f_c} = \frac{1}{f_1} + \frac{1}{f_2}$$

Place the concave lens in contact with the convex lens (convex surface to concave surface) in a lens holder and determine the focal length of the lens combination f_c by finding the image of a distant object. Record the results in the Laboratory Report. Using the equation

$$\frac{1}{f_c} = \frac{1}{f_1} + \frac{1}{f_2}$$

with the focal length of the convex lens determined in procedure 1, compute the focal length of the concave lens.

Appendix A: Computer Simulation Exercises

Introduction:

One of the many conveniences of computers is their powerful ability to simulate natural phenomena. Computer simulations save scientists billions of dollars per year by avoiding expensive experiments in wind tunnels and blast chambers as two examples. Computer simulations can be performed to simulate a phenomenon that we cannot readily access, such as the gas flows inside a star in the process of going supernova, the fluctuations of an atom, and the evolution of a solar system over billions of years' time. Back on Earth, much simpler simulations can be used in the classroom to repeat live experiments using an array of initial conditions, enabling students to see clearly how changing parameters can change the outcome of an experiment.

In this Lab, we are going to run such a simulation. The assignment (which will vary by instructor and class section) is to select an experiment of your choosing in the areas of Thermodynamics, Electricity & Magnetism, Optics, or Modern and run through that experiment several times, virtually, changing the initial conditions and recording the outcomes of each run.

Equipment:

Computer with Internet access (the instructor will decide whether to use the website given below, another website, or a CD-ROM simulation program),
-OR -

Physics Computer Simulation Program found on the laboratory computers (Instructor will give specifics)

Procedure:

There is a large number of simulation packages available, from CD's and DVD's in the Physics Learning Center (NSCI 324), to websites that offer applets and downloads that demonstrate various principles of physics. For this experiment, we will choose one such simulation within the areas mentioned above from a website (to be determined)

Go to the website provided in class, and click on one of the choices in the list. The list includes simulations in the following areas:

- Archimedes' Principle
- The Ideal Gas Law
- The Kinetic Theory of Gases
- The Carnot Cycle and the Efficiency of Engines
- PP Physics in Practice: Gasoline Engines
- Hooke's Law
- Damped Harmonic Motion

- Pulses on a Rope
- Sound Waves
- The Doppler Effect
- Standing Waves on a String
- Beats
- Superposition of Electric Fields
- Electric Resistance and Ohm's Law
- Applications of Kirchhoff's Rules
- Magnetic Forces on Moving Charged Particles
- Generators and Motors
- Electromagnetic Waves
- The RC Circuit
- R-L-C Series Circuit
- Models of Light: Rays and Waves
- Reflection and Refraction
- Thin Lenses
- Locating Images by Ray Tracing.
- The Thin-Lens Equation
- Reflection and Refraction of Light Waves
- Interference of Light
- Dispersion
- Crystals and X-Ray Diffraction
- Spectroscopy
- The Photoelectric Effect
- Successes of the Bohr Theory
- Tunneling or Barrier Penetration
- Colors by Addition and Subtraction
- The pn-junction

Select one or more simulations from this list and do them, varying the parameters and seeing how this varying affects the outcome of the experiment. You could either choose an experiment that will not be done this semester, or an experiment that has been done already. In the latter case, the initial conditions of the experiment can be modified to see how the results differ from that experienced in the classroom.

Your instructor may decide to use the simulation programs included in the Physics Learning Center instead of going online to the above site. Internet problems may result in this as well. Follow the directions given by the instructor and the simulation program(s) being used.

Appendix B: Introduction to the Oscilloscope

By Dr. Kevin Storr

Purpose-Introducing the Oscilloscope

The purpose of this exercise is to learn how to operate an oscilloscope, which includes observing and measuring fast and periodic electrical voltages.

Introduction & Theory

The cathode-ray oscilloscope is an instrument which can be used to display the magnitudes of rapidly changing electric currents, potentials, or pulses as a function of time. The information is displayed on a "cathode ray tube" (CRT). The CRT appears as a circular or rectangular window usually with a centimeter graph superimposed on it. (Of course, a similar cathode-ray tube is also an integral part of your television set.)

The cathode-ray tube consists essentially of an "electron gun" for producing a beam of rapidly moving electrons called cathode rays, a fluorescent screen upon which a luminous spot is produced by the impact of the cathode rays, and a means for displacing the spot from its quiescent position as the result of current or voltage applied to the deflecting mechanism. Although the electron beam may be focused by means of magnetic fields, electrostatic focusing is usually used.

Fig. 1 shows the electrode structure of a typical cathode-ray tube having an electron gun with electrostatic focusing.

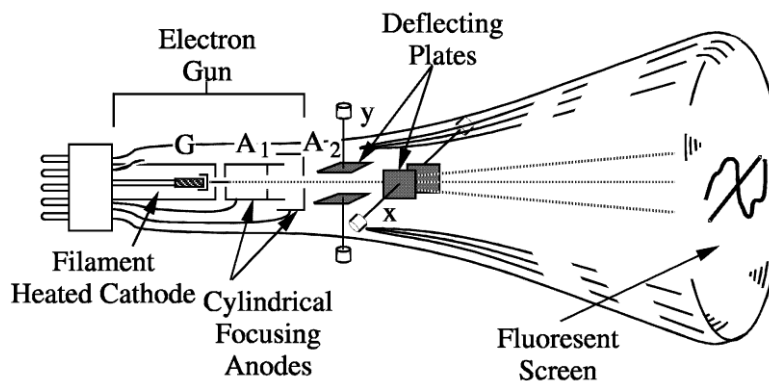


Figure 1

The electron gun consists of an electron source (i.e. an electrically heated cathode which "boils off" electrons), a grid G for controlling the intensity of the electron beam, hence the brightness of the luminous spot, and two anodes A_1 and A_2 . The final velocity with which the electrons leave the gun is determined by the potential of A_2 which is normally maintained constant. The electrostatic fields between G and A_1 and between A_1 and A_2 focus the stream of electrons in a

manner somewhat analogous to the focusing of light rays by lenses. Usually, the focus control on the oscilloscope adjusts the potential of A_1 .

After leaving the electron gun, the electron beam passes between a pair of horizontal plates. A potential difference applied between these plates deflects the beam in a vertical plane in direct proportion to the instantaneous voltage applied between the deflecting plates. This pair of plates provides the y -axis or vertical movement of the spot on the screen. A pair of vertical plates provides the x -axis or horizontal movement of the spot on the screen.

The screen of a cathode-ray tube consists of a thin layer of a phosphor, which is a material that luminesces as the result of bombardment by rapidly moving electrons. The bombardment gives rise to both fluorescence and, emission of light after bombardment. The phosphor is applied to the inside of the end of the tube by spraying, dusting, or precipitation from a liquid. Slow decay of phosphorescence makes possible the visual observation of non-repeating transients and prevents flicker in the visual observation of periodic voltages of low frequency. However, if it is too slow it causes blurring whenever an image on the screen changes form.

The main circuits of an oscilloscope and their functions are described below in (a) through (f). Fig. 1 of **Appendix A** (to this experiment) shows the control areas for these circuits for the Tenma 72-6805 oscilloscope, similarly identified as (a) through (f).

(a) The time-base generator. In order that the image plotted on the scope screen shall show the unknown y -axis voltage as a function of time, it is necessary that the spot shall periodically sweep across the screen horizontally (along x -axis) with uniform velocity up to a certain point and then return rapidly to its zero position. If the time taken for one timing sweep is equal to the period of the voltage applied to the y plates, the pattern will consist of one cycle of the y voltage. If the sweep frequency is equal to f_y/n , the image will show n waves of the y voltage. The required horizontal movement of the fluorescent spot can be produced by means of an x voltage that periodically increases uniformly with time and falls to zero instantaneously upon reaching a given value. The wave form of such a linear sweep voltage is shown in Fig. 2. Because of its shape, this signal is called a "sawtooth" voltage.

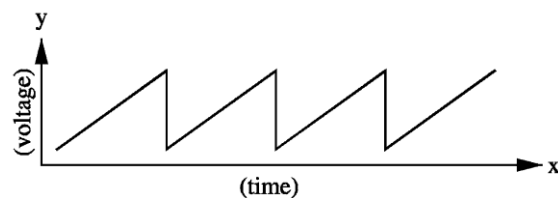


Figure 2

(b) The horizontal and vertical signal amplifiers. The oscilloscope amplifiers serve two purposes. 1) Providing sufficient voltage to give any desired deflection of the electron beam. 2) Making possible the variation of the deflection voltages without drawing appreciable current from the source under observation or from the sweep generator.

(c) **The z-axis modulation** controls the intensity and focus of the electron beam.

(d) and (e) **The synchronization circuit** ties the sweep of the horizontal time-base in with the vertical signal so that any harmonic signal can be displayed as a stationary pattern. The horizontal sweep is begun by a signal or condition called the "trigger." A variety of triggers are available as well as a variety of display selections following the trigger.

(f) **The power supply** provides the various potential differences and currents for complete operation of the instrument.

The individual controls for the above circuits are identified in Fig. 1 of **Appendix A**. The corresponding list of controls and descriptions of their function are given in **Appendix A** as well. Study this list and try to understand the function of as many of the controls as you can before going to the lab. In lab you will experimentally study the functions of most of them.

Equipment

Oscilloscope	1
Function Generator	1
DC Power Supply	1
60 Hz AC Power Source	1
Coaxial Cables	3

Procedure

A. Familiarizing Yourself with the Oscilloscope

- ◆ To prepare the oscilloscope for operation, follow the instructions for "How to Produce the Bright Line" in **Appendix A**. These procedures will avoid damage to the various oscilloscope circuits at turn-on. At the conclusion of these procedures, you will have observed the horizontal line (called a trace). Be sure the trace is not too bright or the electron beam might burn the phosphor on the screen.
- ◆ Now you should analyze and become familiar with the operation and functions of as many of the various controls as you can. Design and perform simple tests for the controls. Since most of these are fairly obvious, you need not record them in your report unless something unusual happens. If it does, of course, you should seek out the reason. Performing **Part B** will help you become acquainted with various controls.

B. Measurement of DC and AC voltages

Note: *Bold italic* numbers below are knobs indicated schematically and described in **Appendix A**. **Also note:** Connections will typically be made with co-axial cables that are terminated by BNC connectors. A coaxial cable consists of a central wire surrounded by a dielectric (typically plastic) which is itself surrounded by a braided copper shield. The signal typically travels on the center wire and the copper shield is grounded. The center post of the BNC connector is attached

to the central wire and the metal twist lock on the BNC connector is attached to the grounded shield. These connections are schematically shown in figures in the next two labs.

Using Channel 1 (CH 1 or X) controls only:

- (1) Set the "DC-GND-AC" Switch **11** on GND.
- (2) Adjust the vertical "position ", knob **19** so the horizontal trace is vertically centered on the screen. Now you can measure voltages relative to this ground position.
- (3) Set the "DC-GND-AC" switch to DC.
- (4) Turn the variable, "VAR" dark gray knob **15**, voltage control fully clockwise. The surrounding light gray knob "VOLTS/DIV" **13**, can be adjusted to change the vertical scale calibration in volts per centimeter above and below the zero (central) or ground position. The calibration is correct **only** when the dark gray knob is fully clockwise. Test this vertical deflection with a 1.5 volt battery connected to the "CH1 INPUT" **9**. Reverse its polarity. Again test the vertical deflection. Now observe the effect of the variable calibration control **15**.
- (5) Set the "DC-GND-AC" switch to AC and repeat the test with the battery and explain what happens. (Hint: refer to **Appendix A**.)
- (6) Repeat (4) but use an AC voltage source, e.g., the AC line source box. With the "TRIGGER MODE" switch **35** at AUTO, set the "TRIGGER SOURCE select switch **31** to CH 1. Adjust the "TRIGGER LEVEL" control knob **34** if the wave display is not stationary. Measure on the horizontal scale the time period of voltage oscillation. Compare your result with $T = 1/f$ for $f = 60$ Hz. The horizontal time scale is chosen by knob **26**, "TIME/DIV". Test what happens when **31** is not set as indicated. **EXPLAIN!** (See **Appendix A**.)
- (7) Reset all controls and replace the AC line source box with the sine wave output of the function generator. Adjust knob **13** so that the sine wave voltage amplitude about fills the CRT, and vary the frequency of the function generator. Start at about **10** Hz and increase by about factors of three to about **100,000** Hz. Calculate the frequency at each interval by measuring the time for a full cycle, as you did in part (6). Compare this measured value with the value you read off the function generator. Which set of values are more precise? Plot these data as frequency against frequency, including appropriate error bars. Does a straight line of slope 1 pass through the data (including 0-0)?
- (8) Disconnect the function generator. Set the horizontal sweep (i.e. TIME/DIV) for 5 ms/cm, turn the vertical gain (i.e. CH 1 VOLTS/DIV) up high so that you can see very small signals, and touch your finger to the center wire of the BNC cable, without touching the grounded outer cable. Adjust the vertical gain until you see a wave pattern with a few centimeters amplitude. Measure the period of the wave and deduce its

frequency. Identify the source of the signal for which your body is serving as an "antenna". (Hint: What else has that frequency?) What is the AC output voltage of your body antenna?

C. Lissajous Figures

Now set the horizontal sweep (i.e., the "TIME/DIV" knob) at the position "X-Y". Then connect the Channel 2 input **10** to the transformer (small yellow box) which is plugged into the AC line power of the laboratory. This box serves as a 60 Hz reference standard. The electron beam of the oscilloscope is now displaced vertically by a sinusoidal potential at a frequency of 60 Hz. Connect the "Sine-Wave" output of the Function Generator to the horizontal input of Channel 1, **9**. Observe the various stationary "Lissajous patterns" which occur as the frequency of the signal generator is varied.

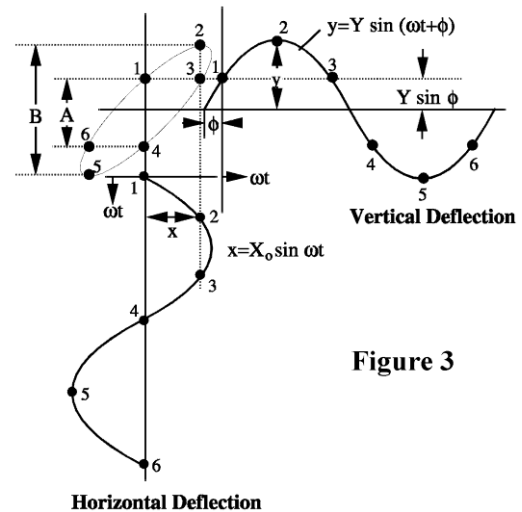


Figure 3

Note: If "TIME/DIV" is set on "X-Y", then the CH 1 input voltage results in a horizontal (x) deflection and a CH2 input voltage gives a vertical (y) deflection. However when "TIME/DIV" is at any of the time settings then the x-axis of display is time while CH 1 or CH 2 inputs give a vertical deflection.

The Lissajous figures can be used to calibrate the Function Generator.

Whenever a stationary pattern is achieved as the frequency is varied, the frequency ratio of the vertical input to the horizontal input is equal to the ratio of the number of horizontal to vertical points of tangency to a rectangle that encloses the pattern (or the ratio of the number of horizontal to vertical axis crossings). Explain why this is true. (Note: Fig. 3 gives a rough sketch of the Lissajous pattern resulting from the X and Y input voltages shown. In this case the frequency ratio $f_x/f_y = 1$ and the phase angle between the two sine waves is about 30° .)

Assuming that the vertical signal is exactly 60 Hz, check a few points on your Function Generator frequency reading (e.g. 30, 60, 90, 120, 240 Hz) and evaluate correction factors if any, for them (i.e. the number which must be added to the generator reading to obtain the actual frequency defined by your standard and the oscilloscope, as a function of generator frequency.)

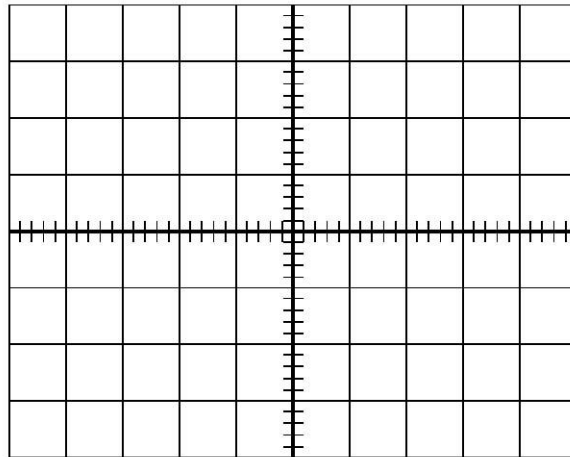
The sine of the phase angle ϕ is given by $\sin(\phi) = A/B$, as defined in Fig. 3. (Can you show this mathematically?) Does this relation uniquely define the phase angle ϕ (in the range $0 - 2\pi$)?

Results-Analog Oscilloscope

Using the settings that were assigned in lab, answer the following questions:

1. What is the setting on the Volts/Div control knob?
2. How many vertical divisions are there from peak-to-peak?
3. What is the peak-to-peak voltage (V_{pp})? Remember $V_{pp} = \text{___ volts/div} \times \text{___ div} = \text{___ volts}$
4. What is the setting on the sec/div control knob?
5. How many horizontal divisions are there?
6. What is the period (T) of the signal? $T = \text{___ sec / div} \times \text{___ div} = \text{___ sec}$.
7. What is the frequency (f) of the signal (in Hertz)?
8. Draw the displayed signal on the graph below. Be neat, to scale, and concise.

Write down the scale (V/div and Sec/div settings) on the graph.

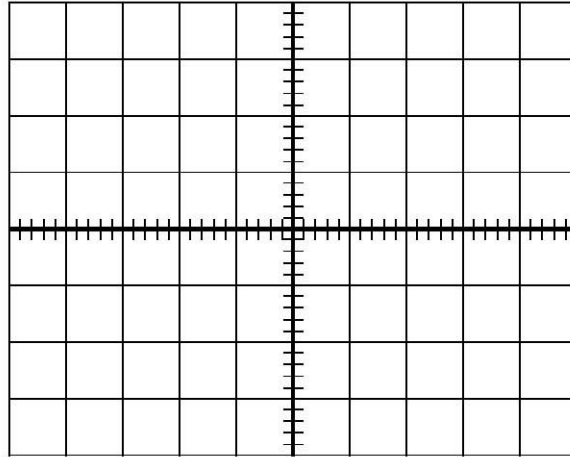


The next part is to adjust the function generator to output another signal and repeat the measurements in Step 1:

1. Generate a sine wave between 5 and 10 kHz with an amplitude setting of at least 6 vertical divisions
2. Adjust the V/div and sec/div settings to maximize the display of the signal on the CRT. Make sure you show the signal from peak-to-peak and at least one full cycle (period) of the signal.
3. What is the setting on the Volts/div control knob?
4. How many vertical divisions from peak-to-peak?
5. What is the peak-to-peak voltage (V_{pp})? $V_{pp} = \text{___ volts/div} \times \text{___ div} = \text{___ volts}$
6. What is the settings on the sec/div control knob?

7. How many horizontal divisions are there?
8. What is the frequency (f) of the signal (Hz)?
9. Draw the displayed signal on the graph (next page)

Write down the scale (V/div and Sec/div settings) on the graph.



Appendix Ba – THE OSCILLOSCOPE: TENMA Model 72-6805

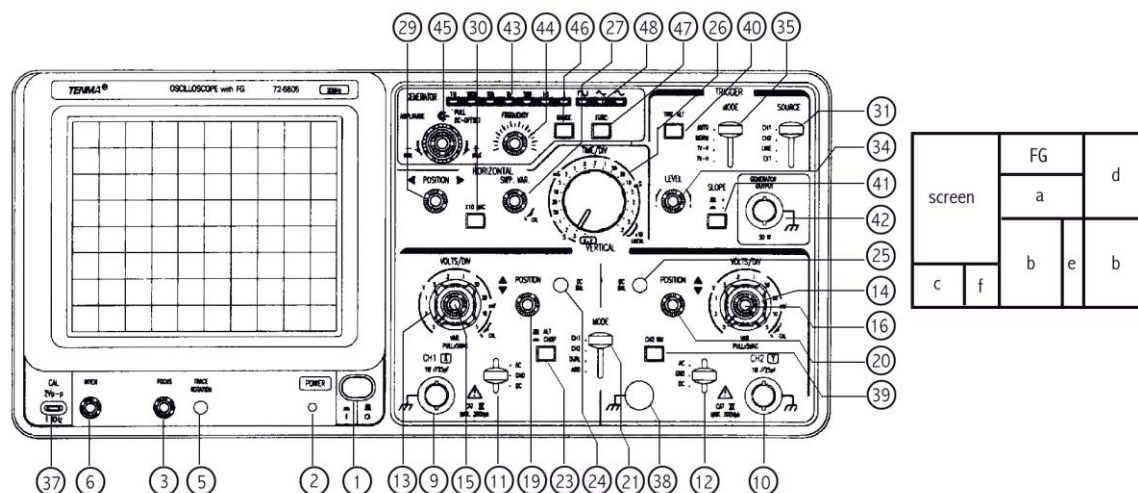


Figure 1

First Time Operation – How To Produce The Bright Line

Before turning on the power, insert the plug of the power cord on the rear panel into the power supply wall socket and set the controls as follows.

POWER (1)	OFF
INTEN (6)	Midrange
FOCUS (3)	Midrange
VERTICAL MODE (21)	CH1
ALT/CHOP (12)	Released (ALT)
AC-GND-DC (11), (12)	GND
VERT. POSITION (19), (20)	Midrange
VOLTS/DIV (13), (14)	0.5V/DIV
VARIABLE (15), (16)	CAL (Rotate fully clockwise.) In this case, the VOLTS/DIV is calibrated to its indicated value.
CH2 INV (39)	Released
TRIGGER MODE (35)	AUTO
TRIGGER SOURCE (31)	CH1
TRIG. ALT (40)	Released
SLOPE (41)	+
TIME/DIVISION (26)	0.5 msec/DIV
HORIZ. POSITION (29)	Midrange
SWP. VAR (27)	CAL (Rotate fully clockwise.)
X10 MAG (30)	Released

After setting the switches and control knobs as mentioned, turn ON the POWER. A trace will appear on the screen in about 20 seconds. Adjust the trace to the appropriate brightness and image sharpness with the INTEN and FOCUS control knobs, respectively.

DESCRIPTION OF THE OSCILLOSCOPE CONTROLS AND CONNECTIONS

1 POWER SWITCH Main power switch of the instrument. The unit is set ON when the switch is at the pushed-in position.	2 POWER LAMP This LED lights up when the main power switch is ON.
3 FOCUS CONTROL Focus the trace to the sharpest image by turning this knob clockwise or counterclockwise.	
5 TRACE ROTATION Used to align the trace of the CRT with the horizontal graticule.	6 INTENSITY control Controls the brightness of the spot or trace. Brightness is increased by turning the INTEN knob clockwise.
7 POWER SOURCE SELECT SWITCH Line voltage selector used to select power sources.	8 AC Inlet Connect the AC power cord (supplied) to this connector.
9 CH1 INPUT Connector Terminal for the input signal to CH1. The input signal to CH1 is the X-axis signal when the oscilloscope is used in X-Y operation.	10 CH2 INPUT Connector Terminal for the input signal to CH2. The input signal to this terminal becomes the Y-axis signal when the oscilloscope is used in X-Y operation.
11, 12 AC-GND-DC Selects the connection mode between the input signal and the vertical amplifier. AC At this setting, the DC component of the signal is cut off and only the AC component is displayed. GND The vertical amplifier input is grounded and input terminals are disconnected. DC At this setting, the input signal is directly connected to the vertical amplifier and is displayed unchanged including the DC component.	13, 14 VOLTS/DIV Selects the vertical axis sensitivity from 5mV/DIV to 5V/DIV with 10 ranges totally. Set this switch to an easily observable range corresponding to the amplitude of the input signal.

<p>15, 16 VARIABLE (VAR.) PULLx5MAG Fine adjustment of sensitivity with a factor of greater than or equal to 1/ 2.5 of the indicated value. For normal operation, this knob must be turned all the way clockwise to the CAL position where the sensitivity is calibrated to the indicated value. When this knob is pulled out (x5MAG) the amplifier sensitivity is multiplied by 5.</p>	<p>19, 20 VERTICAL POSITION Controls This knob is used to adjust the vertical position of the trace or spot.</p>
<p>21 VERTICAL MODE Select Switch Selects the operation modes of the CH1 and CH2 amplifiers. CH1 Operate the oscilloscope as a single channel instrument, displaying the signal applied to CH1 alone. CH2 Operate the oscilloscope as a single channel instrument, displaying the signal applied to CH2 alone. DUAL Operate the oscilloscope as a dual-channel instrument, displaying both signals applied respectively to CH1 and CH2. ADD The oscilloscope displays the algebraic sum (CH1 + CH2) or subtraction (CH1 – CH2) of the two signals. (The subtraction is in effect when the CH2 INV button (39) is pushed in.)</p>	<p>22 CH1 SIGNAL OUTPUT Delivers a voltage of approximately 20mV/DIV from the CH1 signal to 50 ohm terminal for frequency counting. Provides a sample of the signal applied to the CH1 connector.</p>
<p>23 ALT/CHOP Used in conjunction with (21) VERTICAL MODE DUAL trace operation. When the ALT/CHOP switch is released in the DUAL trace mode, the input signals at CH1 and CH2 are alternately displayed (normally used at faster sweep speeds). When this switch is depressed in the DUAL trace mode, the CH1 and CH2 inputs are chopped and displayed simultaneously (normally used at slower sweep speeds).</p>	<p>24 25 DC BAL Adjustment Controls The knobs are used for adjusting the attenuator balance. See oscilloscope manual, p. 20 DC BAL adjustments for details.</p>
<p>26 TIME/DIV Select Switch Provides sweep time ranges from 0.2 uS/div to 0.5 S/div with 20 steps totally. X-Y In this setting the instrument is used as an X-Y oscilloscope where the X (horizontal) signal is the input to CH1 and the Y (vertical) signal is the input to CH2.</p>	<p>27 SWP. VAR The sweep time of the TIME/DIV can be varied continuously when this knob is not at the CAL position. Counterclockwise rotation to the full, delays the sweep by 2.5 times or more. For normal operation, rotate the knob to the CAL position and the sweep time will be calibrated to the preset value of the TIME/DIV switch.</p>
<p>29 HORIZONTAL POSITION CONTROL This knob is used to adjust the horizontal position of the trace or spot. The trace is moved toward the right with clockwise rotation and toward the left with counterclockwise rotation.</p>	<p>30 x10 MAG Magnify by 10 by pressing this button.</p>
<p>31 TRIGGER SOURCE Select Switch Selects the internal triggering source signal, and the EXT TRIG IN input signal. CH1 Select CH1 to get internal triggering source signal. CH2 Select CH2 to get internal triggering source signal. LINE Use the power line frequency signal as triggering signal. EXT Obtain external trigger source signal by applying external signal to the EXT TRIG IN input terminal (33).</p>	<p>33 EXT TRIG IN Input Terminal This input terminal is used for external triggering signal by setting the SOURCE switch (31) to the EXT position.</p>

<p>34 LEVEL This knob is used to decide at which portion of the waveform should the sweep be started by setting the trigger level. This helps to display a synchronized and stationary waveform.</p>	<p>35 TRIGGER MODE Select Switch Trigger mode selection. AUTO The oscilloscope is brought into automatic triggering sweep in which sweep is always conducted. In the presence of a triggered signal, normal triggered sweep is obtained and the waveform stands still. In the case of no signal or out of triggering, the sweep line will appear automatically. This is the usual and convenient setting. NORM Triggered sweep is obtained and sweep is conducted only when triggering is in effect. No sweep line will appear in case of no signal or out of synchronization. Use this mode when effecting synchronization to very low frequencies. TV-V Used for observing the entire vertical picture of television signal. TV-H Used for observing the entire horizontal picture of television signal. (Both TV-V and TV-H synchronize only when the synchronizing signal is negative)</p>
<p>36 Z-AXIS Input Input terminal for external intensity modulation signal.</p>	<p>37 CAL 2V p-p This terminal delivers the calibration voltage of 2 V p-p, 1 KHz, positive square wave.</p>
<p>38 GND Terminal Ground terminal of oscilloscope mainframe.</p>	<p>39 CH2 INV When this button is pressed, the CH2 input signal is inverted and in the ADD mode, the CH2 signal is also inverted.</p>
<p>40 TRIG/ALT If you set VERT MODE (21) to DUAL or ADD, press CH1 or CH2 on the TRIGGER SOURCE switch (31), then press the TRIG/ALT button, the internal triggering source signal will display alternately from CH1 and CH2.</p>	<p>41 SLOPE Triggering slope button. “+” Triggering occurs when the trigger signal crosses the trigger level by positive going course. “-” Triggering occurs when the trigger signal crosses the trigger signal by negative going course.</p>

The TENMA Model 72-6805 Oscilloscope also provides the basic features of a Function Generator to satisfy general demand with simple and intuitional operation by adjusting the control knobs directly from the front panel for output waveform, amplitude, frequency and range. All the function generator control knobs are located in the front panel with the same color.

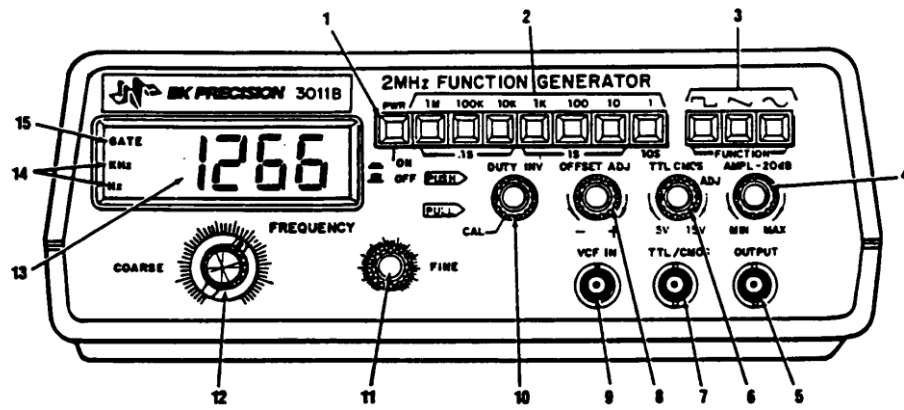
42 GENERATOR OUTPUT This is the main output terminal of the function generator with 50 ohms impedance.	43 FREQUENCY RANGE DISPLAY The selected frequency range is lighted up on this display panel.
44 FREQUENCY KNOB This knob is used to adjust the frequency. Rotate the knob clockwise to get higher frequency and rotate counterclockwise to get lower frequency.	45 AMPLITUDE/DC OFFSET Adjustment Knob The outer knob is used to adjust the amplitude of the wave. Rotate clockwise to increase the amplitude and rotate counterclockwise to decrease the amplitude. The inner knob is for DC Level adjustment and works only when the knob is pulled up. Pull up the knob and rotate clockwise to get positive DC Level and reverse the rotation of the knob to get negative DC Level.
46 FREQ RANGE Switch The frequency range can be selected by pressing this button , following 1M, 100k, 10k, 1k, 100, 10 and 1 sequence.	47 WAVEFORM SELECTOR Pushing this button will change the waveform following a Sine wave, Triangle wave and Square wave sequence.
48 OUTPUT WAVEFORM DISPLAY The current output waveform is lighted up on this display panel.	

Appendix Bb - The Function Generator

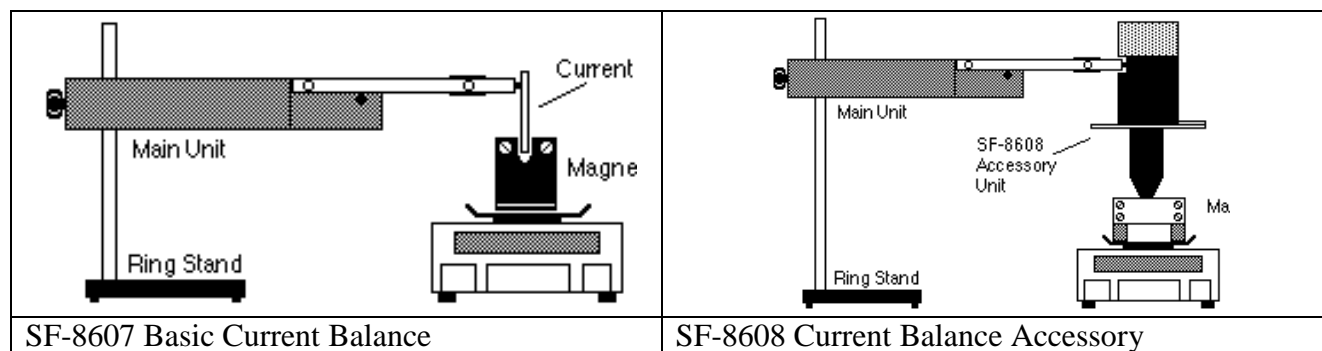
Controls and Indicators

1. PWR Switch. Turns power on and off.	2. Range Selectors. Selects frequency range. Decade frequency type, seven ranges from 1 Hz to 1 MHz. Frequency can be adjusted from 0.2 to 2 times the range selected. For example, if the 100 K range is selected, frequency can be adjusted (see Frequency Control) from 20 kHz to 200 kHz. Numbers under pushbuttons indicate gate time (see GATE LED)
3. Function Selectors. Selects square, triangle, or sine waveform at OUTPUT jack.	4. AMPL Control. Controls amplitude of signal at OUTPUT jack. When control is pulled out, signal is attenuated 20 dB (PULL -20 dB).
5. OUTPUT Jack. Waveform selected by FUNCTION switches as well as the superimposed DC OFFSET voltage is available at this jack	6. TTL/CMOS. When control is pushed in, a TTL signal is present at the TTL/CMOS jack. Level is fixed at 3 V p-p and turning control has no effect. When the control is pulled out (PULL CMOS), a CMOS signal is present at the TTL/CMOS jack. Turning the control clockwise increases the amplitude and turning the control counterclockwise decreases amplitude (amplitude is adjustable from approximately 4 V p-p to 14.5 V p-p).
7. TTL/CMOS Jack. Square wave selected by TTL/CMOS control (either TTL or CMOS) is available at this jack. The output is independent of the AMPL and OFFSET controls.	8. OFFSET Control. When control is pushed in, DC offset is set at zero. When control is pulled out (PULL ADJ), clockwise rotation changes DC offset in a positive direction and counterclockwise rotation changes DC offset in a negative direction. Full clockwise rotation gives approximately +5 V into 50 load (+10 V open circuited). Full counterclockwise rotation gives approximately -5 V into 50 load (-10 V open circuit).
9. VCF IN Jack. Voltage Controlled Frequency input. Permits external sweep or frequency control. Positive voltage decreases the output frequency.	10. DUTY Control. Rotation adjusts the duty cycle of both the main OUTPUT signal and the TTL/CMOS signal. Fully counterclockwise rotation is the CAL position (normal duty cycle). Duty cycle changes when control is rotated away from CAL position. When control is pulled out (PULL INV), the square wave at the main OUTPUT and the TTL or CMOS signal are inverted.
11. FINE Frequency Control. Vernier adjustment of output frequency for ease of setting to a precise frequency.	12. COARSE Frequency Control. Coarse adjustment of output frequency (main output and TTL/CMOS output) from .2 to 2 times the selected range.
13. Frequency Counter Display. Displays frequency of internally generated frequency.	14. Hz and kHz LED. Indicates whether display is showing Hz or kHz.
15. GATE LED. Indicates when frequency counter display is updated. When the 10 K through 1 M frequency switches are selected, the LED will flash 10 times per second (every 0.1 second). When the 10 through 1 K switches are selected, the LED will flash once each second and when the 1 switch is selected, the LED will light every 10 seconds. As the LED turns off, the display is updated.	

Figure 2



APPENDIX C: Experiments in Magnetic Force with PASCO's Basic Current Balance and Current Balance Accessory



What follows are four experiments, one of which can be used for the Magnetic Force Experiment. These experiments come courtesy of PASCO scientific, who have provided the equipment and the user's manual which contain these experiments.

Experiment 1: Force versus Current

Procedure

If you're using a quadruple-beam balance:

- ① Set up the apparatus as shown in figure 1.1.
- ② Determine the mass of the magnet holder and magnets with no current flowing. Record this value in the column under "Mass" in Table 1.1.
- ③ Set the current to 0.5 amp. Determine the new "mass" of the magnet assembly. Record this value under "Mass" in Table 1.1.
- ④ Subtract the mass value with the current flowing from the value with no current flowing. Record this difference as the "Force."
- ⑤ Increase the current in 0.5 amp increments to a maximum of 5.0 amp, each time repeating steps 2-4.

If you're using an electronic balance:

- ① Set up the apparatus as shown in figure 1.1.
- ② Place the magnet assembly on the pan of the balance. With no current flowing, press the TARE button, bringing the reading to 0.00 grams.
- ③ Now turn the current on to 0.5 amp, and record the mass value in the "Force" column of Table 1.1.
- ④ Increase the current in 0.5 amp increments to a maximum of 5.0 amp, each time recording the new "Force" value.

Data Processing

Plot a graph of Force (vertical axis) versus Current (horizontal axis).

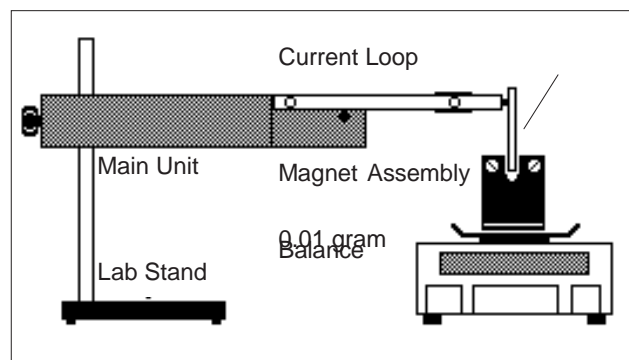


Figure 1.1 Equipment Setup

Analysis

What is the nature of the relationship between these two variables? What does this tell us about how changes in the current will affect the force acting on a wire that is inside a magnetic field?

Table 1.1 Data

Current (amps)	“Mass” (gram)	“Force” (gram)	Current (amps)	“Mass” (gram)	“Force” (gram)
0.0			3.0		
0.5			3.5		
1.0			4.0		
1.5			4.5		
2.0			5.0		
2.5					

Please attach a typed Conclusions/Discussion section addressing any questions asked by your instructor (do the same for each of the four magnetic force experiments).

Experiment 2: Force versus Length of Wire

Procedure

- ① Set up the apparatus as in Figure 2.1.
- ② Determine the length of the conductive foil on the Current Loop. Record this value under “Length” in Table 2.1.

If you are using a quadruple-beam balance:

- ③ With no current flowing, determine the mass of the Magnet Assembly. Record this value on the line at the top of Table 2.1.
- ④ Set the current to 2.0 amps. Determine the new “mass” of the Magnet Assembly. Record this value under “Mass” in Table 2.1.
- ⑤ Subtract the mass that you measured with no current flowing from the mass that you measured with the current flowing. Record this difference as the “Force.”
- ⑥ Turn the current off. Remove the Current Loop and replace it with another. Repeat steps 2-5.

If you are using an electronic balance:

- ③ Place the magnet assembly on the pan of the balance. With no current flowing, press the TARE button, bringing the reading to 0.00 grams.
- ④ Now turn the current on, and adjust it to 2.0 amps. Record the mass value in the “Force” column of Table 2.1.
- ⑤ Turn the current off, remove the Current Loop, and replace it with another. Repeat steps 2-4.

Data Processing

Plot a graph of Force (vertical axis) versus Length (horizontal axis).

Analysis

What is the nature of the relationship between these two variables? What does this tell us about how changes in the length of a current-carrying wire will affect the force that it feels when it is in a magnetic field?

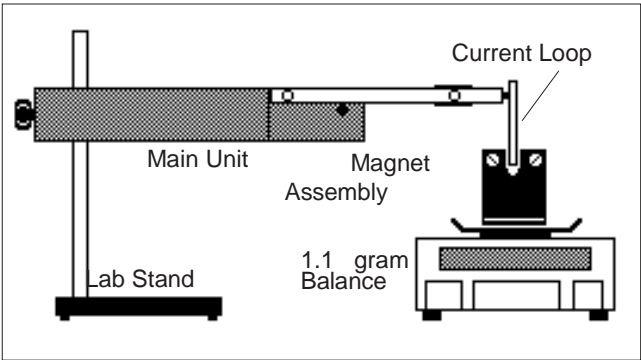


Figure 2.1 Equipment Setup

“Mass” with I=0: _____

Table 2.1 Data

Length (mm)	“Mass” (gram)	“Force” (gram)	Length (mm)	“Mass” (gram)	“Force” (gram)

Experiment 3: Force versus Magnetic Field

Procedure

① Set up the apparatus as shown in Figure 2.1. Use the shortest length current loop.

If you are using a quadruple-beam balance:

② Mount a single magnet in the center of the holder.

③ With no current flowing, determine the mass of the Magnet Assembly. Record this value in the first column under “Mass” in Table 3.1 on the appropriate line.

④ Set the current to 2.0 amps. Determine the new “mass” of the Magnet Assembly. Record this value in the second column under “Mass” in Table 3.1.

⑤ Subtract the mass you measured when there was no current flowing from the value you measured with current flowing. Record this difference as the “Force.”

⑥ Add additional magnets, one at a time. (Make sure the north poles of the magnets are all on the same side of the Magnet Assembly.) Each time you add a magnet, repeat steps 3-5.

If you use an electronic balance:

② Use a single magnet, centered under the center of the holder.

③ Place the magnet assembly on the pan of the balance. With no current flowing, press the TARE button, bringing the reading to 0.00 grams.

④ Now turn the current on, and adjust it to 2.0 amps. Record the mass value in the “Force” column of Table 3.1.

⑤ Add additional magnets, one at a time. (Make sure the north poles of the magnets are all on the same side of the Magnet Assembly.) Each time you add a magnet, repeat steps 3-5.

Data Processing

Plot a graph of Force (vertical axis) versus Number of Magnets (horizontal axis).

Analysis

What is the relationship between these two variables? How does the number of magnets affect the force between a current-carrying wire and a magnetic field? Is it reasonable to assume that the strength of the magnetic field is directly proportional to the number of magnets? What would happen if one of the magnets were put into the assembly backwards, with its north pole next to the other magnets’ south poles? If there is time, try it.

Table 3.1 Data

Number of Magnets	”Mass”		”Force” gram	Number of Magnets	”Mass”		”Force” gram
	I = 0 gram	I ≠ 0 gram			I = 0 gram	I ≠ 0 gram	
1				4			
2				5			
3				6			

Experiment 4: Force versus Angle

Procedure

1. Set up the apparatus as shown in Figure 4.1.

If you are using a quadruple-beam balance:

2. Determine the mass of the Magnet Assembly with no current flowing. Record this value in Table 4.1 on the appropriate line.
3. Set the angle to 0° with the direction of the coil of wire approximately parallel to the magnetic field. Set the current to 1.0 amp. Determine the new “mass” of the Magnet Assembly. Record this value under “Mass” in Table 4.1.

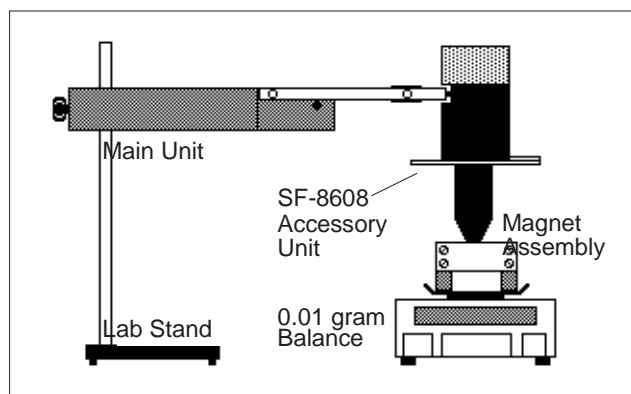


Figure 4.1 Equipment Setup

4. Subtract the mass measured with no current flowing from the mass measured with current flowing. Record the difference as the “Force.”
5. Increase the angle in 5° increments up to 90° , and then in -5° increments to -90° . At each angle, repeat the mass/force measurement.

If you are using an electronic balance:

2. Place the magnet assembly on the pan of the balance. With no current flowing, press the TARE button, bringing the reading to 0.00 grams.
3. Set the angle to 0° with the direction of the coil of wire approximately parallel to the magnetic field. Set the current to 1.0 amp. Record the mass value in the “Force” column of Table 4.1.
4. Increase the angle in 5° increments up to 90° , and then in -5° increments to -90° . At each angle, repeat the mass/force measurement.

Data Processing

Plot a graph of Force (vertical axis) versus Angle (horizontal axis).

Analysis

What is the relationship between these two variables? How do changes in the angle between the current and the magnetic field affect the force acting between them? What angle produces the greatest force?

What angle produces the least force?

Table 4.1 Data “Mass” with $I = 0$:

Angle (θ)	“Mass” (gram)	“Force” (gram)	Angle (θ)	“Mass” (gram)	“Force” (gram)	Angle (θ)	“Mass” (gram)	“Force” (gram)
0			50			0		
5			55			-5		
10			60			-10		
15			65			-15		
20			70			-20		
25			75			-25		
30			80			-30		
35			85			-35		
40			90			-40		
45						-45		

APPENDIX D: Magnetic Fields Laboratory Package

Pre-Laboratory Exercise #D: Magnetic Fields

Name: _____

Course: _____

Date: _____

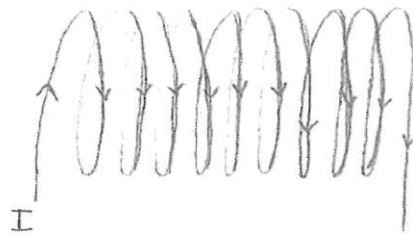
1. Draw a good representation of the magnetic field lines produced by the bar magnet shown on the back of this page.
2. Draw a good representation of the magnetic field lines produced by the solenoid shown on the back of this page.

The magnitude of the magnetic field along the axis of an N-turn coil (Helmholtz coil) is

$$B = \frac{\mu_o N I R^2}{2(x^2 + R^2)^{3/2}}$$

where I is the current, R is the radius of the coil, and x is axial distance from the coil's center.

3. What is the magnitude of the magnetic field at the center of a 100-turn Helmholtz coil of radius 5.0 cm carrying an 0.5-A current? _____
4. What is the magnitude of the magnetic field produced by that Helmholtz coil at a point on the solenoid's axis 3.0 m from its center? _____



Laboratory D—Magnetic Fields

Purpose

The purpose of this experiment is to understand magnetic fields and how they behave through the mapping of the field lines and through investigations of electromagnetism. An optional set of computer simulations is included near the end.

Introduction and Theory

A magnetic field is a vector force field generated by a magnetic dipole that can exert a force on a moving electric charge or another magnetic dipole. Field lines are used to graphically indicate the direction of the field, and the density of the lines indicates the strength of the field. These force fields can also be generated by electric currents of various sizes. These currents can be macroscopic, as is the case in electromagnets, or microscopic, as is true for permanent dipole or bar magnets. In the microscopic case, the magnetic field arises from electrons in atomic orbits. The magnetic field, \vec{B} , is defined in terms of a force exerted on a moving test charge, as exhibited by the Lorentz Force Law:

$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$

The direction of the electric force is in the direction of the electric field if the charge on the test charge q is positive, but the direction of the magnetic field is given by the right hand rule. The magnetic field has units of Tesla and Gauss, where 1 Tesla = 10,000 Gauss.

The magnetic field due to a wire segment, Δs , is given by the Biot-Savart Law:

$$\Delta \vec{B} = \frac{\mu_0 I}{4\pi r^3} \Delta s \times \vec{r}$$

with $\mu = 4\pi \times 10^{-7} \text{ Tm/A}$.

For complete circuits, such as a circular loop of wire with a loop radius of R and N turns:

$$\vec{B} = \frac{\mu_0 N I R^2}{2(x^2 + R^2)^{3/2}}$$

From the right hand rule, with the fingers curled in the direction of electric current flow in the loop, the thumb points in the direction that the magnetic field points-along the axis of the current loop.

Current loops act like magnetic dipoles with a dipole moment of $\mu = IA$, with A being the area of the loop. Coils of wire only produce magnetic fields when carrying electric current. The magnetic field of such a setup drops as $\frac{1}{R^3}$ at large R .

At large x , the magnetic field equation becomes $\frac{\mu_0 N I R^2}{2x^3}$. At a distance, the magnetic field from the loop is equivalent to that of a small permanent magnet.

Note: This lab has several variations which are included below. The standard report sheet with its procedure is also included. The professor may decide to do one or the other (or a combination of both).

Equipment

Bar magnet	1
Neodymium or Rare Earth Magnet	1
Horseshoe magnet	several
Small compass	1
Solenoid with iron core	1
800 turn coil	1
DC Power supply	1
Ammeter & Voltmeter (or multimeter)	1 each
Connecting wires	4
Graph paper (can use the same as was used in the Electric Field Mapping experiment)	Several sheets
PC with Internet connection and Data Studio	1
Magnetic Field Sensor	1

Procedure

Note: this experiment is a collection of demonstration activities that explore the permanent magnet as well as the electromagnet. The instructor may choose one or more of the suggested activities, or perform one of his own choosing to demonstrate how magnetic fields work. Included below are several activities, which consist of both online and live, hands-on exercises. In addition, there are several demonstrations (e.g. jumping ring, magnet through a Helmholtz coil hooked to a galvanometer, Lenz's law, etc.) that can be performed to illustrate concepts covered in this experiment.

1. Permanent Magnet

The first activity involves mapping the magnetic field in a manner similar to what we did earlier in the semester with the electric field. In this case, it is considerably simpler. We will use small compasses ("magneto-probes") to trace out the magnetic field at various places to put together a picture of the magnetic field. We will do this for several different types of magnets.

To map out the magnetic field of a bar magnet, follow the guidelines listed below:

- ◆ Set the magnet near the center of the sheet of graph paper
- ◆ Starting about 1cm on one side of the magnet, near the middle, place the compass until the needle stabilizes (do not drop the compasses)
- ◆ Draw a point on the paper on either side of the points of the compass needle
- ◆ Move the compass up or down one compass diameter and repeat. Follow the direction of the needle, if it begins to turn, make sure you turn with it
- ◆ Continue this process, connecting the dots as you go along, until you reach a pole of the magnet.
- ◆ Repeat for the other end, toward the other pole, and also for the other side of the magnet at an equivalent distance.

- ◆ After having plotted the first pair of magnetic field lines, repeat the above steps for lines that parallel the magnet about 3cm, 5cm, 7cm and 10 cm away from the magnet.

If the instructor chooses, he may have you map the magnetic field that surrounds a different type of magnet. If so, repeat the above steps for that magnet on a separate sheet of paper.

2. Solenoids and Wire Coils

This next activity makes use of the wire coils in the following manner, starting with the solenoid. There are several questions in the procedure that you will need to write responses for in the Results section of your laboratory report.

- ◆ Connect the solenoid coil, without its core, to a DC power supply.
- ◆ Turn on the power and adjust the potential to 10V (you may wish to verify this setting with the voltmeter).
- ◆ Bring the core into the opening of the solenoid, about $\frac{3}{4}$ the way inside. Turn on and off the power supply and observe how this affects the core—does it tug on the core as you switch on and off?
- ◆ Does the coil attract the core in a certain direction or is one end of the core repelled?
- ◆ Does the core have permanent north and south poles?

We will repeat part of the above procedure with the 800 turn coil, but use the magnetic field sensor attached to the Science Workshop interface box and with DataStudio running. Place the sensor inside and outside, at various distances, and perform the following tasks:

- ◆ Connect the 800-turn coil to a DC power supply.
- ◆ Turn on the power and adjust the potential to 10V (you may wish to verify this setting with the voltmeter).
- ◆ Measure the current, I , with the ammeter and record it in the Results section data table. Measure the R , or radius, of the coil loops
- ◆ Calculate the magnetic field for a point at the center of the cavity of the coil loop using the equation $\vec{B} = \frac{\mu_o N I R^2}{2(x^2 + R^2)^{3/2}}$. Repeat at distances (from the side of the coil near the middle) of $2R$, $3R$, $5R$, and $10R$.
- ◆ At what point would you use $\frac{\mu_o N I R^2}{2x^3}$?
- ◆ Take measurements of B at the same locations for which you did calculations. How do the calculated and measured values compare to each other? To better evaluate this, calculate the percent difference between the measured and the calculated values. How does the field drop off as you move away from the coil (you may wish to plot this to get a better idea of this)?

$$\%diff = \left| \frac{B_{calculated} - B_{measured}}{B_{calculated}} \right| \cdot 100\%$$

Data and Results

Attach the map(s) of the magnetic field(s) you made from Part I to this write up. If you mapped two fields, how were they similar? How were they different? Did all of your field lines make closed loops? (Material from the computer simulation section can go on the back of this sheet, if this activity is performed). You may use the following data sheet or construct your own, or use an alternative one provided by your instructor.

Solenoid observations:

The 800-turn coil: Radius = _____ N = _____ I = _____

R	R, m	B-field Measured	B-field Calculated	% Difference
center				
2R				
3R				
5R				
10R				

3. Computer Simulations (Optional Extension to the Lab)

If instructed by your professor, you will do a simulation that is provided by the University of Colorado's Simulation Library. Go to "Faraday's Electromagnetic Lab" on the following website:

http://phet.colorado.edu/simulations/sims.php?sim=Faradays_Electromagnetic_Lab

Click on "run now" to launch the simulation (you may need to press the "Ctrl" button as you click "run" to enable the popup window to appear). There are five tabs for five activities: bar magnet, pick up coil, electromagnetic, transformer, and generator. We will do all five. Answer all the questions posed in the five activities below in the discussion section of your laboratory report.

I. Bar Magnet

On the screen you should have a bar magnet and a compass.

1. Compare the magnetic field around the bar magnet (represented by the little arrows) to the *electric* field around a positive and negative charge.
2. Use the magnetic field sensor to find the strength of the magnetic field at 8 points spread out around the magnet. Sketch the magnet, and at these points, draw a vector (with size and direction) that represents the field.
3. Use the magnetic field sensor to find the magnetic field *inside* the magnet. Explain your findings.
4. Measure the magnetic field strength at 10 points along a straight line extending out from the magnet's south pole. As there is no measuring tape on this simulation, use a ruler against the screen to measure distance in cm. Make a graph of magnetic field vs. distance (attach to this write up).

II. Electromagnet

Go to the "Electromagnet" tab.

1. Sketch the electromagnet. Label the parts and show what is happening in the electromagnet to create a magnetic field.
2. How does the magnetic field compare to that of a bar magnet?
3. What things can you change in the simulation that affects the magnetic field? List the options, and explain the resulting change in the field.
4. What physical factor in the electromagnet determines where the "north" and "south" pole of the magnet is located?

III. Pickup Coil

Go to the "Pickup Coil" tab and investigate the equipment. Explain 2 ways that you can get the light bulb to light. What factors determine how brightly the light shines?

IV. Transformer

Investigate the setup of this experiment. Run once with the battery-powered (DC current) electromagnet to get the light bulb to shine. Do it again with the AC current. What do you notice that is different when the AC current is run versus the DC current?

What else can you change about the pickup coil? How does that change the outcome of the experiment?

V. Generator

What is happening in this experiment and how do things change with the changing flow of water? Change out the light bulb for the meter. How does the meter behave as you change the flow of water that drives the generator?

How does this demonstration relate to the power generation methods of some locations in the U.S.?

Write your responses after each section of the simulation sequence.

Lab #8 Report Sheet: Magnetic Fields

Experimenters: _____

Course: _____

Date: _____

Part 1: Magnetic field of bar magnet (attached).

Part 2: Measure the Earth's magnetic field.

Part 3: Field strength along axis of a Helmholtz coil.

Data Tables

N (# of turns)	R (radius)	V (voltage)	R (resistance)	I (current)
200	10.5 cm		7.1 Ω	0.4 A

x	B (measured)	B (theoretical)	% Difference
0 cm			
5 cm			
10 cm			
15 cm			
17 cm			
19 cm			
21 cm			
23 cm			
25 cm			

Attach a plot of the measured B versus x .

Summary

Attach a typed Summary. Include the following:

- 1.** What did you find for the strength and orientation of Earth's magnetic field?
- 2.** How did your measurements compare to your theoretical expectations both for the field lines of a bar magnet and for the quantitative measurements of the magnetic field strength along the axis of the Helmholtz coil?
 - 2a.** Is the dependence of the magnetic field strength of Helmholtz coil with distance along the axis as expected?
 - 2b.** Does the field fall off as x^{-3} with large distance as expected? At what distance does this behavior begin?
- 3.** Discuss factors that could have influenced your quantitative measurements and what you did to minimize them.